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SURVEY OF PERFORMANCE ASSURANCE CONCEPTS APPLICABLE TO BASELOAD--ETC(U)

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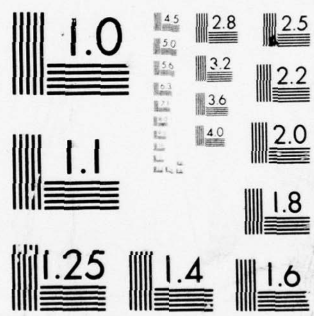

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SURVEY OF PERFORMANCE ASSURANCE CONCEPTS APPLICABLE TO BASELOAD ELECTRIC POWERPLANTS

November 1977

See back page for 1473

Prepared for
FEDERAL ELECTRIC UTILITY PROGRAM TASK FORCE
U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545
under P.O. EX-77-X-01-4120

ARINC RESEARCH CORPORATION

SURVEY OF PERFORMANCE ASSURANCE CONCEPTS
APPLICABLE TO BASELOAD
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Prepared for

Federal Electrical Utility Program Task Force
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ABSTRACT

This report provides an overview of performance assurance practices developed and applied since World War II to improve the cost-effectiveness of selected, large-scale technological systems. The purpose is to present concepts which might be applicable in reducing the frequency and duration of electric powerplant outages. A comprehensive performance assurance program is recommended. The elements of the suggested program were derived by considering elements of precedent programs which are believed to be most effective in other applications.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

A work plan for the Federal Electric Utility Program Task Force was set forth in a joint FEA-ERDA memorandum dated July 1, 1977.* A principal activity described was the development of a Department of Energy (DoE) program for improving baseload powerplant performance. To carry out the activity, a Powerplant Performance Working Group was organized with representatives of the Federal Energy Administration (FEA), the Energy Research Development Administration (ERDA), and the Federal Power Commission (FPC).

The Working Group was activated on August 19, 1977, and assigned to conduct a study and submit (1) a recommendation for a comprehensive DoE program and (2) an assessment of the potential benefits to be derived from improved powerplant performance. The study was to identify program requirements for legislation, research, development, demonstration, technical assistance, and standards development, as well as the DoE resources needed for implementation.

Under Purchase Order No. EX-77-X-01-4120, dated September 9, 1977, the executive steering committee requested ARINC Research Corporation to perform a complementary study in parallel with the Working Group's efforts.

1.2 RATIONALE FOR THE ARINC RESEARCH STUDY

Electric utilities must have generating capability to meet peak demand; in consequence, a part of their plant is idle when demand is less than peak. The need to reduce this idle baseload capacity grows in importance as pressures increase to hold the line on costs, as siting and licensing constraints make it more difficult to add new capacity, and as the nation attempts to conserve scarce energy resources.

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*Memorandum to Jack O'Leary (Administrator, FEA) and Robert Fri (Acting Administrator, ERDA) prepared by William Fischer (Associate Administrator for Policy and Program Analysis, FEA) and David Israel (Assistant Administrator for Field Operations, ERDA).

One approach is to implement a formal performance assurance program aimed at reducing the frequency and duration of powerplant outages. If such a program could be applied successfully, it would be possible for less baseload capacity to provide adequate reserve margins.

The problem of achieving the maximum reduction in the frequency and duration of both forced and scheduled outages is equivalent to that of reducing the failure rate, repair time, and preventive maintenance time associated with each critical component as well as the system as a whole. This problem is typically addressed in the normal course of applying traditional procurement and engineering practices. However, as technology changes and systems (i.e., powerplants) become larger and more complex, it may be cost-effective to augment traditional procurement and engineering practices in such a way as to focus more emphasis on plant reliability, maintainability, and quality assurance. Furthermore, it may be appropriate to organize and share the effort on a broader-than-local scale.

1.3 STUDY OBJECTIVES

The objectives of the ARINC Research study were to review the substance of performance assurance programs applied by selected government agencies and industries and to derive from experience in such agencies and industries a comprehensive performance assurance program to be considered for application in the electric power industry.

1.4 STUDY APPROACH

The approach was to interview persons responsible for developing or applying performance assurance programs in selected agencies and companies and to review and analyze program documents identified during these interviews. Program elements identified by interviewees as being of substantial value in the context of their own experience were then combined and fitted together to form a comprehensive, recommended program for application in the electric power industry. ARINC Research Corporation made the final judgments concerning which program elements to include in the recommended program. However, in making these judgments, we tried to consider and incorporate a spectrum of other perspectives. We found the following proceedings and reports to be most valuable in understanding these other perspectives:

- "Proceedings of the Reliability Engineering Conference for the Electric Power Industry", February 1974.

  "A Report on Improving the Productivity of Electric Powerplants", FEA Interagency Task Group on Powerplant Reliability, March 1975.

  "Electrical Generating Plant Availability", FPC Bureau of Power Staff Report, May 1975.

  "Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations", IEEE Draft Standard P577/02/REV2, April 1976.

- "Proceedings of the Executive Conference on Improving Power Plant Reliability", September 1976.
- "Use of Nuclear Plant Operating Experience to Guide Productivity Improvement Programs", prepared by M.E. Lapides and E. Zebroski, Electric Power Research Institute, November 1976.
- "Draft Guidelines for Incorporating Performance Assurance Requirements in Fossil Energy Research, Development and Demonstration Contracts", Assistant Administrator for Fossil Energy, Energy Research and Development Administration (ERDA), May 20, 1977.
- "Proceedings of the Fourth Reliability Engineering Conference for the Electric Power Industry", June 1977.
- "Availability of Fossil-Fired Steam Power Plants", Special Report FP-422-SR, prepared by Don Anson, Electric Power Research Institute, June 1977.

1.5 SCOPE OF THE STUDY

1.5.1 Individuals Interviewed

More than fifty persons were interviewed by telephone to identify individuals with detailed knowledge of performance assurance programs and practices and obtain information necessary to focus the effort. Of the individuals so identified, those located in the Washington - Annapolis area were interviewed face-to-face; they are identified in Table 1-1.

1.5.2 Content of the Interviews

The interviews were structured around questions relating to the scope and specific content, background, age, management, and organization of performance assurance programs in which the interviewee had a major role. Most persons interviewed had many years of experience in developing and managing formal performance assurance programs and could therefore offer valuable insights concerning the key elements, cost, and effectiveness of formalizing performance assurance.

The principal emphasis during the interviews was to identify and concentrate on those elements or aspects of the program which interviewees believed to be most cost-effective. These elements and aspects were identified by asking the following questions:

- Which elements or aspects have you found most cost-effective in:
  - Detecting and correcting failure causes and mechanisms during pre-operational phases?
  - Reducing maintenance costs?
  - Reducing repair and replacement costs?
  - Reducing redundancy requirements?

Table 1-1. INDIVIDUALS WHO CONTRIBUTED TO THE STUDY IN FACE-TO-FACE INTERVIEWS

M. Barrett Staff Supervisor AT&T Long Lines	F. Newhouse ARINC Service Manager AT&T Long Lines
E. J. Boyle Chief, System Safety Division Urban Mass Transit Administration	T. Palmer District Engineer C&P Telephone Company (Toll Terminals)
H. Frankel Assistant Director Materials and Power Generation Fossil Energy U.S. Department of Energy	H. D. Short ARINC National Account Manager AT&T Long Lines
J. J. Genovese Assistant Deputy Chief of Naval Material, Logistics Naval Material Command	F. Starbuck Assistant Director for Facilities and Equipment Engineering Directorate Goddard Space Flight Center
C. J. Heltemes, Jr. Chief, Quality Assurance Branch Division of Project Management U.S. Nuclear Regulatory Commission	Colonel B. H. Swett Military Assistant to the Assistant Director of Planning U.S. Department of Defense, ODDR&E
A. Lakner Chief, Reliability and Maintainability Systems Engineering Federal Aviation Administration	F. T. Taylor Director, Bureau of Accident Investigation National Transportation Safety Board
A. J. Moskovitz Chief, Office of Space Science Program Assurance NASA Headquarters	W. J. Willoughby, Jr. Assistant Deputy Chief of Naval Material, Reliability & Engineering Naval Material Command

  - Reducing acquisition costs?
  - Reducing performance assurance costs?
  - Reducing program support costs?
- Which elements or aspects of your program are most enthusiastically accepted by:
  - General management?
  - Engineering management?
  - Government?
  - Contractors and suppliers?
  - Customers, consumers, users?
- Which elements or aspects of your program were derived from experience in other agencies or industries, i.e., which are commonly applicable in a broad spectrum of technological situations?

- Are you changing any element or aspect of your program, and
    - Why?
    - How?
- Which elements or aspects of your program could be applied most effectively if you were acquiring a system under the following circumstances?
    - System requires 12 years to plan, design, build, and test.
    - The useful life of major system components is 30 to 40 years.
    - System costs $1 billion to build.
    - The cost of replacement production due to outages is $250,000 to $1 million per day.
    - The number of prime contractors and major suppliers is small.
    - In-house capability is oriented to operations rather than to design, development, and installation.
    - Users of system output are very sensitive to interruptions in output and price of output.

1.5.3 Performance Assurance Programs Selected for Review and Analysis

Although the initial goal was to analyze private-sector as well as government programs, the results are heavily biased by the character and experience of government programs. Private-sector concern over the proprietary nature of its programs made it difficult, in the short time available for the study, to gain access to key documents defining performance assurance programs of private organizations.

Performance assurance programs in the following agencies and companies were reviewed and analyzed:

- U.S. Department of Defense
- National Aeronautics and Space Administration
- Federal Aviation Administration and the commercial airline industry
- The National Transportation Safety Board
- Urban Mass Transit Administration
- U.S. Nuclear Regulatory Commission
- The Bell System (AT&T)

Performance assurance programs in the U.S. Department of Energy, such as those developed for application to the Clinch River Breeder Reactor Project (CRBRP) and fossil energy projects, were reviewed also; but they are in a preliminary stage and yielded no results considered appropriate for inclusion in this report.

1.5.4 Key Documents

Key documents describing and defining formalized performance assurance programs in the selected agencies are identified in Table 1-2.

1.6 GUIDE TO THIS REPORT

The results and recommendations are presented in Chapter Two. A comprehensive performance assurance program to be considered for application in the electric power industry is outlined there.

The information gathered during the interviews and from pertinent references is presented in seven appendixes. Each appendix except Appendix C describes performance assurance programs in a single agency or industry. Appendix C deals with the performance assurance programs of both the Federal Aviation Administration and the commercial airline industry. Each appendix is organized in the following manner: First, the historical development and general scope of performance assurance practices are described. Second, the potential applicability of specific practices to the power industry is addressed. Third, those practices which seem most worthy of further consideration are described in more detail. Finally, some indications of the cost and effectiveness of the program from which the applicable practices were drawn are offered.

Agency	Reference Number	Document
DoD	A-1	DoD Directive 5000.1 - Acquisition of Major Defense Systems
OMB	A-2	OMB Circular A109 - Major System Acquisition
DoD	A-3	MIL STD 785 - Reliability
DoD	A-4	MIL STD 470 - Maintainability
DoD	A-5	DoD Directive 5000.3 - Test and Evaluation
NASA	B-1	NHB 5300.4(1B) (Formerly NPC 200-2) - Quality Program Provisions for Aeronautical and Space System Contractors
NASA	B-2	NHB 5300.4 (1A) (Formerly NPC 250-1) - Reliability Program Provisions for Aeronautical and Space System Contractors
FAA	C-1	FAA-G-2100/1b - Electronic Equipment, General Requirements
FAA	C-2	Reliability/Maintainability Systems Engineering Program Plan, FAA, Airways Facilities Service
UMTA	E-1	MARTA Reliability Program Plan - Metropolitan Atlanta Rapid Transit Authority
NRC	F-1	Code of Federal Regulations, Title 10, Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Processing Plants
	F-2	NUREG-75/087, Section 17.1 - NRC Standard Review Plan, Quality Assurance During the Design and Construction Phase
	F-3	NUREG-75/087, Section 17.2 - NRC Standard Review Plan, Quality Assurance During the Operations Phase

Table 1-2. CITED KEY DOCUMENTS

CHAPTER TWO

RESULTS AND RECOMMENDATIONS

2.1 RESULTS OF THE SURVEY

The characteristics of performance assurance in the selected agencies, industries, and companies are summarized in Table 2-1. Although each agency or firm among those surveyed tends to emphasize different aspects of performance assurance depending upon its charter and history, there are large areas of general agreement. The overall finding is that most performance assurance programs are evolving in similar ways to fulfill a common need. This need is to improve the effectiveness of the contractual arrangement between operators of large, interconnected, and expensive systems and their system acquisition contractors and suppliers.

2.1.1 The Performance Assurance Function

All respondents agree that performance assurance is primarily an acquisition management concept aimed at identifying and correcting potential operating deficiencies early in the acquisition process. Most respondents point out that system acquisition and system operation are separate and distinct management functions and that the performance assurance function is to assure that operating imperatives are addressed during the acquisition process.

2.1.2 Implementing Performance Assurance

The consensus is that the acquisition contractual document is the principal vehicle for applying a formal performance assurance program; i.e., most respondents emphasize that the assurance aspect of a formal program is contractual in nature.*

Most respondents agree that a formal approach to performance assurance is most cost-effective, particularly in situations in which the system acquisition process involves many subcontractual arrangements, involves large and continual commitments of capital, and extends over many years. In such circumstances, the majority opinion holds that it is important to

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*Respondents in regulatory agencies such as NRC tend to emphasize the legislative aspect of assurance. However, even regulatory requirements must ultimately be addressed in the contractual document.

Table 2-1. CHARACTERISTICS OF PERFORMANCE ASSURANCE IN SELECTED AGENCIES, INDUSTRIES, AND COMPANIES

Factor	Department of Defense	National Aeronautics and Space Administration	Federal Aviation Administration and Airlines	Federal Aviation Administration National Airway System	Urban Mass Transit Administration	Nuclear Regulatory Commission	National Transportation Safety Board	American Telephone and Telegraph
System Characteristics								
Primary System Type	Combat systems	Missile, spacecraft, and control systems	Aircraft, engines, and avionics	Command, control, and communication systems	Transit and control systems	Nuclear reactors	Transportation systems	Communication systems
Life Characteristics	10-20 years	A few days to several years	10-20 years	5-15 years	15-25 years	20-40 years	15-50 years	5-20 years
Technology Status	Pushes state of the art	Pushes state of the art	State of the art	State of the art	Limited new technology	Existing technology	Existing technology	Limited new technology
Operation Requirement	Missions vary from several hours to continuous operation	Missions vary from a few hours to continuous operation	Daily operation for period of 10-16 hours	Daily operation for period of 16 hours to continuous operation	Daily operation for period of 10-16 hours	Continuous operation with periodic shutdown for maintenance	Various	Continuous
Uses Standard Equipment	Limited	Very limited	Broad use	Limited	Policies established to encourage use	Limited	No	Broad usage
System Acquisition Policies								
Sponsors System R&D	Yes	Yes	Limited	Yes	Limited	No	No	Yes
Funds Acquisition	Yes	Yes	No	Yes	Partial	No	No	Yes
Operates System	Yes	Yes	No	Yes	No	No	No	Yes
Performance Assurance Program								
Primary Concern	Reliability, maintainability, availability, cost	Reliability, availability, cost	Safety, reliability, maintainability, cost	Safety, reliability, maintenance, cost	Safety, security, reliability, maintainability, cost	Safety and security	Safety	Availability, maintenance, cost
Implementation Authority	Specifications applied through contracts	Specifications applied through contracts	Certification authority	Specifications applied through contracts	Funding program approval	Certification authority	Investigative authority	Corporate directives
Quantitative Goals	Yes	Yes	No	Yes	Yes	No	No	Yes
Formal Program	Yes	Yes	No	Yes	Yes	Yes	No	Limited
Formal Quantitative Demonstration Test	Yes	No	No	Yes	No	No	No	No
Qualification Testing	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Operational Feedback	Yes	Yes	Limited	Yes	No	Yes	Limited to accident investigations	Yes

codify or formalize even common-sense practices which traditionally have been taken for granted, and to define responsibility and authority for implementing these practices in an explicit way.

2.1.3 Delegation of Effort

All respondents agree that it is important to divide, apportion, and share the performance assurance effort among all participants interested in system acquisition and operation. Within the electric power industry, that sharing should be between the national level, the acquiring entities, and the contractors and suppliers.

2.1.3.1 National Effort

The degree of public vs. private control over system performance varies among the agencies and firms surveyed to an extent that precludes agreement concerning an overall national effort. However, it is possible to identify elements that reflect a consensus on policies and practices of a majority. A national program comprising such elements is described in Table 2-2.

2.1.3.2 Local Effort

All agree that the lead authority and responsibility for implementing performance assurance should rest with the organization responsible for acquiring the system. A minimal effort by the acquiring entity which fits the consensus is described in Table 2-3.

2.1.4 The Evolution of Performance Assurance Programs

Although performance assurance programs have evolved differently in all agencies and firms surveyed, there is a perceptible common trend in all.

Typically, the first step is an attempt to utilize failure, maintenance, and cost experience with one system to improve the design of another. Initially, this experience is transferred in an informal way from operating engineers to design engineers via professional societies, trade journals, or person-to-person contact.

Subsequently, an information system is established to provide quantitative but generic data for use in identifying critical problem areas. These data are then used by design engineers to estimate potential performance.

In time, the information system and data base are refined to the point where statistically valid performance prediction becomes possible.

Table 2-2. RECOMMENDED ELEMENTS OF A COMPREHENSIVE NATIONAL* PERFORMANCE ASSURANCE EFFORT

- Articulate national performance goals and measures.
- Estimate the value and cost of realizing national performance goals.
- Sponsor the development of training programs.
- Sponsor the development of guidelines for implementing local-level programs.
- Sponsor the development and refinement of performance reporting systems.
- Sponsor the development and refinement of specialized techniques and models.
- Sponsor the development of centralized test facilities.
- Sponsor the development of centralized failure analysis facilities.
- Develop, in cooperation with state and local governments and regional cooperatives, appropriate incentives for improving performance.
- Sponsor product improvement research.

*A national effort does not necessarily imply a Federal Government role. For example, AT&T centralizes and coordinates the Bell System performance assurance program through Western Electric and Bell Telephone Laboratories. A performance assurance program for application in the electric power industry could be centralized and coordinated at the national level by industry associations.

Table 2-3. PERFORMANCE ASSURANCE EFFORT BY THE ACQUIRING ENTITY*

- Define explicit measures of cost-effective operational performance, considering regulatory requirements where necessary.
- Introduce quantitative operational performance goals into acquisition contracts.
- Require acquisition contractors to present a plan for achieving performance goals, i.e., a performance assurance program plan.
- Review and evaluate contractor's and supplier's performance assurance programs.

*E.g., an electric power utility.

It is at this juncture that various agencies and firms decide whether to incorporate quantitative performance goals into acquisition contracts. Typically they decide to try, and they seek precedents for doing so. In almost every case, the precedents can be ultimately traced to DoD-sponsored activities.

In trying to incorporate quantitative performance goals into the acquisition process, each agency and firm typically faces the fundamental problem of demonstrating conformance. Each has five interrelated alternatives:

1. Devise tests to quantitatively demonstrate system performance after the system is built.
2. Devise tests to quantitatively demonstrate subsystem performance as the system is designed.
3. Forget the need to demonstrate performance quantitatively; test to failure, analyze, and fix.
4. Forget the need to demonstrate performance quantitatively; rely on engineering judgment and review.
5. Rely on standard equipment.

Once an agency or firm has faced these choices, it becomes possible to develop a mature performance assurance program involving an appropriate compromise between the five choices. In effecting this compromise, it is helpful to utilize specialized analytic techniques aimed at transferring and translating the results of quantitative measures of performance at subsystem levels to the system level and vice-versa. These analytic techniques have been developed and are being further developed as the five choices become apparent to more and more agencies and firms.

At this juncture in the evolution of a typical performance assurance program, the problem of monitoring and evaluating contractual performance becomes paramount due to the necessity of evaluating a mixture of quantitative and qualitative measures throughout the acquisition process. Most respondents solve this problem by periodically evaluating the contractor's performance assurance program against the contractor's own program plan.

In a highly evolved program, the operating agency or firm requires a system or subsystem performance warranty. The warranty approach assigns a major portion of the responsibility and effort for assuring system performance to contractors and subsystem suppliers.

The ultimate performance assurance program, i.e., a very highly evolved one, employs sophisticated models for trading off various aspects of system performance. A typical evolution to the highest state involves the increasingly cumulative consideration of:

- Subsystem reliability
- Subsystem maintainability

- System availability
- System life-cycle cost
- Subsystem redundancy
- System interconnection
- System redundancy

2.1.5 Specifying Performance Goals

Most respondents set quantitative performance goals in their requests for proposals as a means of guiding contractors and suppliers in developing an appropriate performance assurance program. However, all recognize that demonstration of performance at the system level against quantitative goals is very expensive and often impossible from a rigorous mathematical viewpoint. Therefore, most accept a combination of analysis and demonstration as evidence of achievement.

2.1.5.1 Specifying Reliability Goals

Reliability goals are most often expressed in terms of mean time between failures (MTBF) or failure rate. A typical approach is to specify the mean time between forced outages at the system or major subsystem level, leaving it to the acquisition contractor or suppliers to allocate the goal to lower levels in the system and present a plan for demonstrating achievement.

2.1.5.2 Specifying Maintainability Goals

Maintainability goals are typically specified in terms of mean time to repair (MTTR). Quantitative maintainability goals are set to guide the preparation of an integrated logistics plan or a maintenance* plan; i.e., quantitative maintainability goals are typically set to stimulate the identification of critical maintenance problems early in the system acquisition process. Most respondents do not require demonstration of achievement, but evaluate the methods and techniques for minimizing downtime. There is growing interest in methods and devices for detecting signs of abonormal wear and adjusting maintenance actions to these signs.

2.1.5.3 Specifying Availability Goals

Most respondents do not set quantitative availability** goals although all point out the need to trade off reliability and maintainability goals against other performance measures such as life-cycle cost. There is a growing tendency, as agencies and firms become more aware of differences in acquisition and operating requirements, to specify availability or some other

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*Maintenance, as used herein, includes preventive maintenance, repair, and replacement. For applications in the electric power industry, maintenance would include all actions related to the overall goal of minimizing the duration of forced and scheduled outages.

**One simple measure of availability is MTBF/(MTBF + MTTR).

combined measure of reliability and maintainability and then determine reliability and maintainability goals as necessary to minimize life-cycle costs.

2.1.5.4 Specifying Life-Cycle-Cost Goals

Although life-cycle-cost goals are rarely specified in acquisition contracts, all respondents agree that there is a trend in that direction. Life-cycle costs include all acquisition and operating costs.

2.1.6 Specifying Redundancy

Reliability, maintainability, and availability may be improved through product improvement or by providing redundant alternatives. Redundancy may be provided at any level in the system hierarchy. Although redundancy is typically specified only for safety-critical items, all respondents recognize the importance of being able to evaluate product improvement vs. redundancy alternatives as they affect life-cycle cost.

2.1.7 Specifying Operating Profiles, Levels of Stress, and Derating Requirements

All respondents emphasize the importance of specifying operation profiles, levels of stress, and derating requirements in the acquisition contract. Most specify operating environmental conditions precisely and in quantitative terms, if possible.

2.1.8 Specifying Rates of Technological Change

Few respondents specify the degree and rate of technological change except indirectly by calling out standard equipments.

2.1.9 Requiring a Performance Assurance Program Plan

All respondents require contractors and suppliers to present formal performance assurance plans as part of their proposals. Typically, the acquiring entity prescribes program requirements in the request for proposal by calling out appropriate performance assurance program standards or guides.

Among the items which all respondents agree should be addressed in the contractual program plan are those shown in Table 2-4.

2.1.10 Cost and Effectiveness of Contractual Performance Assurance

It was not possible to obtain detailed information concerning the cost and effectiveness of applying contractual performance assurance in the short time available for the study. The number of factors to be considered is too large. Nevertheless, it is possible to draw some general and qualitative conclusions.

Table 2-4. PERFORMANCE ASSURANCE ITEMS REQUIRED OF CONTRACTORS AND SUPPLIERS

- Performance Assurance Management and Evaluation Plan
- Training and Indoctrination Plan
- Subcontractor and Supplier Control Plan
- Design Specifications
  - •• Operating specifications
  - •• Environmental specifications
  - •• Reliability specifications
  - •• Maintainability specifications
  - •• Availability specifications*
  - •• Life-cycle-cost specifications*
  - •• Redundancy specifications*
- Performance Prediction and Estimation Plan
  - •• Requirements
  - •• Techniques
  - •• Data
- Iterative Failure Modes and Effects Analysis (FMEA) Plan
- Design Review Plan
- Problem Failure Reporting and Correction Plan
- Standardization of Design Practices
- Parts and Materials Program Plan
- Configuration Management Plan
- Test Plan
  - •• Quantitative demonstration tests
  - •• Test to failure, analyze, and fix
  - •• Qualification tests
  - •• Performance assurance documentation plan
  - •• Warranty plan* or plan for contracter and supplier involvement during operation.

*These items are considered desirable, but are not yet typical requirements in contractual program plans.

2.1.10.1 Cost of Contractual Performance Assurance

The incremental cost of applying a formal performance assurance program during the acquisition of Typical DoD and NASA systems adds from one to ten percent to the cost of the system. However, there are indications that the incremental cost of applying performance assurance during the acquisition of mass transit systems adds only about 0.01 to 0.2 percent to the cost. Apparently, mass transit systems, like electric power plants, contain many standard components and a large proportion of relatively massive and immobile structures that add considerably to the system cost wihtout adding much to the performance assurance burden.

2.1.10.2 Incremental Performance Assurance Cost-Effectiveness

Most respondents agree that the cost-effectiveness is greatest if contractual performance assurance is applied as early as possible in the acquisition process. Indications are that pre-contract planning and iterative design technique* offer the greatest payoff for the smallest expenditure.

All respondents recognize that the cost of improving system performance increases rapidly with system MTBF and the reciprocal of system MTTR. Thus the cost-effectives decreases rapidly as the system's performance improves.**

Most respondents would agree that the cost-effectiveness or performance assurance increases as system acquisition cost increases. Our rationale for this rule is simply that outages are more costly as the payback burden increases. A corresponding rule, derivable from the above, is that cost-effectiveness of performance assurance decreases as the payback schedule is extended.

2.2 RECOMMENDATIONS

Before deciding whether or not a comprehensive performance assurance program based on the results of the survey is applicable in the electric power industry, it would be helpful to address the following questions:

1. To what extent do electric utilities employ performance assurance practices similar to those summarized?

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*Iterative design technique involves continual or stage-by-stage performance analysis and testing during the design process.

**There are possible exceptions to this rule. If the dominate measure of effectiveness involves loss of life or social risk, it is possible to argue that almost any performance assurance cost is justifiable.

2. What are the major economic, institutional, and technical constraints in the electric power industry that might preclude or impede the application of performance assurance practices such as those summarized?

3. Assuming that the answers to the above questions indicate that a comprehensive program such as that summarized can be suitably modified for application in and acceptance by the electric power industry, how, at what rate, and by whom should the program be implemented?

Because the system acquisition contract is such an important mechanism in implementing performance assurance, it is recommended that the U.S. Department of Energy sponsor the development of model performance assurance contracts for voluntary use by the electric power industry. The development effort should include:

- Analysis of current contractual documents used by electric power utilities in acquiring new baseload capacity
- Comparison of contractual performance assurance practicies in the electric power industry to those found effective by others
- Estimation of the costs and benefits of implementing selected contractual practices in the electric power industry
- Formulation of model contractual documents for review by electric utlities and their acquisition contractors
- Definition of strategies for stimulating the expanded use of contractual performance assurance requirements by electric utilities and their acquisition contractors

APPENDIX A

PERFORMANCE ASSURANCE AS PRACTICED BY THE U.S. DEPARTMENT OF DEFENSE

1. HISTORICAL DEVELOPMENT

The current DoD performance assurance activities had their origin in the early 1930s. Major General Leslie E. Simon* traces one line of development from the publication of Dr. Walter A. Shewhart's "Economic Control of Manufactured Product" in 1931** recommending the application of statistical methods to controlling quality (SQC), an approach which was tried at Picatinny Arsenal in 1936 and applied throughout World War II. Near the end of that war, statistical and probabilistic methods were applied successfully by operations researchers (OR) assigned to the staffs of military commanders to analyze alternative operational plans. By the end of the war, the SQC and OR concepts became joined in what subsequently became the basis for reliability assurance. By 1948, quantitative methods were being applied by the Rand Corporation to evaluate the reliability of guided missiles.† By 1950, Dr. Robert Lusser had enunciated a concept of reliability for application in achieving reliability in guided missiles.†† Subsequently the problem of organizing to manage reliability was addressed# and, by 1952, reliability assurance was emerging as a quantitative discipline separate and distinct from the quality control discipline.

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*L. E. Simon, "The Relation of Engineering to Very High Reliability", *Proceedings, Tenth National Symposium on Reliability and Quality Control*, 1964, pp 226.

**W. A. Shewhart, "Economic Control of Quality of Manufactured Product", D. Van Nostrand Co., N.Y., 1931.

†D. J. Davis, "Concepts and Methods for Investigation of Guided Missile Reliability", Rand Corp., Report R-107, November 1948.

††Naval Air Missile Test Center, "A Study of Methods for Achieving Reliability of Guided Missiles", Tech. Report No. 75, July 1950.

#"Final Report of Subcommittee on Reliability of the RDB Guided Missile Committee", Department of Defense, March 1952.

During World War II complex electronic systems were created which in many cases were quite unreliable. This problem led to a number of studies in the late 1940s and early 1950s which investigated the failure patterns of these systems. These studies culminated when the Advisory Group on Reliability of Electronic Equipment (AGREE), Office of the Assistant Secretary of Defense, in 1957 issued a report on recommendations for quantitative control of reliability including testing. From these efforts, a series of specifications were issued by the various military services as part of system acquisition establishing reliability as a controlled parameter.

The reliability development was followed in the early 1960s by the inclusion of maintainability as a contractually specified parameter. In a series of studies the military investigated the nature of equipment maintenance; those studies led to the formation of specifications and supporting techniques.

In the 1963-65 period, the Air Force sponsored the "Weapon System Effectiveness Industry Advisory Committee (WSEIAC), whose purpose was to integrate reliability, maintainability, and performance characteristics into an overall concept called system effectiveness. The developed concept met the objectives stated but due to the complexity of applications, limited use has been made to date. No specifications directly resulted from this effort.

As progress was made in reliability and maintainability as they relate to mission effectiveness, it soon became apparent that they also seriously affected life-cycle cost. In recognition of this concern for life-cycle cost and mission effectiveness along with the need for thorough testing, an approach to meet these needs was given in DoD Directive 5000.1, Acquisition of Major Defense Systems issued in 1971 (Key Document A-1). This document called for a series of major program review points at which the performance, cost, and program risks were assessed before authorization to proceed to the next phase was given. Performance assurance considerations form a vital part of the review process due to its impact on both effectiveness and life-cycle cost.

In 1976 the Office of Federal Procurement Policy issued OMB Circular A109 (Key Document A-2), which expanded the DoD phased concept by requiring the detailed study of mission needs prior to embarking on system development. In essence the mission need should generate system requirements rather than the system defining the mission. Zero based budgeting, which has emerged in this same period, requires the investigation of alternate concepts and their attendant benefits and costs. Such analysis focuses much attention on performance and cost and their underlying drivers.

2. SCOPE OF CURRENT DOD PRACTICES

2.1 Introduction

The DoD performance assurance program consists of two major areas. First, there is the activity associated with system research and development and acquisition or procurement. The second area is associated with system operation and maintenance. The practices in each area will be reviewed in Sections 2.2 and 2.3.

The DoD assurance program is continuing to change and it is difficult to adequately characterize its nature. There also exist differences among the individual services in emphasis and detailed approach. The current program was developed during an era characterized by very poor reliability levels. This was also an era during which the principal emphasis was on developing systems with high technical performance characteristics. More recently, cost has become an increasingly important consideration. The current trend is to place at least as much emphasis on reducing system life-cycle costs as on improving technical performance.

As background to the concepts used, it is of interest to review the organization structure of the services as it relates to the system life cycle and to the type systems which they acquire.

Within the military services, the system acquisition, maintenance and support, and the operations functions are separate and distinct entities. The operations group generates requirements for a system that are addressed during design, development, and procurement. Upon installation and delivery the operating activity uses the system and provides on-site maintenance. Their operation is supported by a logistics activity which provides spare parts and overhaul (off-site) maintenance. Although this structure permits specialists to operate in each area, communication of requirements between organizations is a continuing problem.

It is also important to note that many of the systems employed within the military were designed and developed expressly for those services. They accordingly sponsor the underlying research and development leading to the production item. Efforts are being made to use commercial off-the-shelf items but it is expected that most of the combat-related equipment will continue to be specially designed.

2.2 Acquisition Procedures

The Department of Defense tailors its performance assurance program to meet specialized requirements by calling out specifications and standards in the acquisition contract. An example of a typical call-out is shown in Figure A-1.

APPLICABLE DOCUMENTS

All documents referenced under this paragraph shall be applicable only as specified within this Statement of Work. In the event of any conflict in requirements between applicable documents, the following order of precedence shall prevail: (a) This Statement of Work; (b) ARINC documents; (c) FAA documents; (d) military documents; and (e) other documents. Documents listed herein shall be the latest revision as of the date of contract solicitation.

SPECIFICATIONS

MIL-D-1000	Drawing, Engineering and Associated List
MIL-S-5002	Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-W-5086	Wire, Electric, PVC Insulated Copper or Copper Alloy
MIL-B-5087	Bonding, Electrical, and Lighting Protection for Aerospace Systems
MIL-W-5088	Wiring, Aircraft, Selection and Installation of
MIL-E-5400	Electronic Equipment, General Specification for
MIL-C-5414	Computer, Air Navigation, Dead Reckoning, Type MB-4A and CPU-26A/P (C-141 only)
MIL-E-6051	Electromagnetic Compatibility Requirements, Systems
MIL-E-7016	Electrical Load and Power Source Capacity, Aircraft Analysis of
MIL-E-7080	Electrical Equipment, Aircraft, Selection and and Installation of
MIL-F-7179	Finishes and Coatings, Protection of Aerospace Weapon Systems, Structures and Parts, General Specification for
MIL-M-7793	Meter, Time Totalizing
MIL-I-8700	Installation and Test of Electronic Equipment in Aircraft, General Specification for
MIL-A-8806	Sound Pressure Levels in Aircraft, General Specification for
MIL-A-8860	Modification for Aircraft Strength and Ridigity, General Specification for

(continued)

Figure A-1. TYPICAL SPECIFICATION AND STANDARD CALL-OUT FOR DOD EQUIPMENT PROCUREMENT

SPECIFICATIONS (continued)

MIL-A-8865	Aircraft Strength and Rigidity, Miscellaneous Loads
MIL-A-8868	Aircraft Strength and Rigidity, Data and Reports
MIL-Q-9858	Quality Program Requirements
MIL-D-9898	Drawing, Tube Bend
MIL-N-18307	Nomenclature and Identification for Electronic, Aeronautical and Aeronautical Support Equipment Including Ground Support Equipment
MIL-W-25140	Weight and Balance Control System for Airplanes and Rotocraft
MIL-I-25992	Indicator, Bearing Distance and Heading ID-526A/ARN and ID-798/ARN (C-141 only)
MIL-C-27500	Cable, Electrical, Shielded and Unshielded
MIL-I-27848	Indicator, Horizontal Situation, AQU-4/A (C-141 only)
MIL-C-38037	Computer, Central Air Data, CPU-43/A (C-141 only)
MIL-C-38999	Connector, Electrical, Circular, Miniature, High Density Quick Discount, Environmental Resistant, Removal Crimp Contacts
MIL-M-43719	Marking Materials and Markers, Adhesive, Elastomeric, Pigmented
MIL-I-45208	Inspection System Requirements
MIL-H-46855	Human Engineering Requirements for Military Systems, Equipment and Facilities
MIL-C-81659	Connector, Electrical, DPX
MIL-W-81044	Wire, Electric, Copper or Copper Alloy
MIL-C-83723	Connector, Electrical, Circular, Environmental Resisting, General Specification for
MIL-C-5191(V)	Pitot Static True Air Speed Computer and Transmitter (C-135)
MIL-G-25591B	Gyroscope, Rate, Switching, Type MC-1
MIL-C-8780A	N-1 Compass System (C-135)
MIL-C-8412A	J-4 Compass System (C-135)

(continued)

Figure A-1. (continued)

SPECIFICATIONS (continued)	
MIL-C-38240	Altitude Computer, Altitude Encoder, CPU-66/A-1, Bendix (C-135)
MIL-G-25597	MD-1 Vertical Gyro (C-135)
STANDARDS	
MIL-STD-100	Engineering Drawing Practices
MIL-STD-130	Identification Markings of U.S. Military Property
MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-704	Electrical Power Aircraft, Characteristics and Utilization of
MIL-STD-721	Definition of Effectiveness - Terms for Reliability, Maintainability, Human Factors and Safety
MIL-STD-756	Reliability Prediction
MIL-STD-781	Reliability Tests, Exponential Distribution
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production
MIL-STD-863	Preparation of Wiring Data
MIL-STD-882	Systems Safety Program for Systems and Associated Subsystems and Equipment, Requirements for
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities
MIL-STD-1521	Technical Review and Audits for Systems, Equipment and Computer Programs
MIL-STD-749	Military Standard Preparation and Submission of Data for Approval of Nonstandard Parts

(continued)

Figure A-1. (continued)

HANDBOOKS	
MIL-HDBK-217	Strength of Metal Aircraft Elements
MIL-HDBK-217	Reliability Stress and Failure Rate Data for Electronic Equipment
AFSC DH Series 1-4, 1-6, 2-1, and 2-2	Design Handbooks for Aerospace Systems
MANUALS	
TACM/PACAF/ USAFEM 55-40	Computer Air Release Systems Procedure
TD-3 (Formerly AFSCM/AFLCM 310-1)	DOD Authorized Data List
AFM 800-XX	Computer Resources Acquisition and Support
AIR FORCE REGULATIONS	
AFR 80-28	Engineering Inspections
AFR 800-14	Management of Computer Resources in Systems

Figure A-1. (continued)

2.2.1 Reliability Programs

Two key DoD documents controlling performance assurance are MIL-STD-785, Reliability, and MIL-STD-470, Maintainability (Key Documents A-3 and A-4). The approaches used in both areas are similar; but since reliability has received greater attention, we will focus on this program.

The major elements for reliability control are summarized from MIL-STD-785 in the following subsections.

2.2.1.1 Reliability Program. The contractor is required to establish and maintain an effective reliability program that is planned, integrated, and developed in conjunction with other design, development, and production functions to permit the most economical achievement of overall program objectives. The required reliability program involves consideration of management and technical resources, plans, procedures, schedule, and controls for the work needed to assure achievement of reliability requirements. The program is adjusted to suit the type and phase (design, development, or production) of the procurement. DoD requires that the program be consistent with the severity of the mission requirements, the complexity of the design, the need for commonality, the quantity under procurement, and manufacturing imperatives. The required program must assure reliability involvement throughout all aspects of the design, development, and production as necessary to meet the contractual reliability requirements.

The contractor's proposed program plan describes how he plans to conduct the reliability program to meet the requirements of the request for proposal and the statement of work, in order to comply with applicable reliability program elements. The plan is submitted as a separate and complete entity within the contractor's proposal. The reliability program plan, as approved by the procuring activity, is incorporated into the contract and becomes the basis for contractual compliance.

2.2.1.2 Quantitative Requirements. The system's mission-responsive reliability requirements and objectives are specified contractually. In addition, the minimum acceptable reliability requirements for the hardware are specified. Quantitative hardware reliability requirements for all major subsystems and equipments are included in appropriate sections of the system and end-item specifications. DoD requires that the values not established by the procuring agency be established by the system or equipment contractor at a contractually specified control point prior to detail design.

2.2.1.3 Reliability Demonstration. DoD requires that the achievement of minimum acceptable hardware reliability requirements be demonstrated by means of tests and analyses specified in the contract.

2.2.1.4 Standards Program. The DoD has attempted to use standard items (equipment, modules, components, etc.) as a means of achieving system reliability. The concept is that by the use of a standard item the infant mortality experienced for each new type of item is eliminated. There are also cost advantages that conceptually make this approach very appealing. Major progress has been made by the services in developing and using standard items at the part or component (e.g., resistor, integrated circuit) and at the equipment (e.g., TACAN, IFF) levels. Although some efforts have been directed at forming and using standard electronic modules, the utility of this approach has not been proven.

2.2.1.5 Test Programs. The basic thrust of the current DoD reliability and maintainability programs as they are now evolving is the performance of a series of design tests to determine the ability of the item to operate for some time in the face of mission environments. Although the contractors who normally supply the DoD have available to them the necessary test facilities, the DoD has built and maintains special test facilities used as part of the system development process.

As part of the DoD current "fly before buy" concept (DoD 5000.1), attention has been given to testing prototype systems prior to proceeding with production. To assist in the evaluation of prototype as well as initial operational assessment of first production items, the DoD has established test agencies within the military services whose purpose is to provide an independent assessment of the new system.

2.3 Operational Concepts

The performance assurance program, as it applies to operations, is defined primarily by the maintenance management procedures in a series of directives and manuals. In essence, the system provides for reporting the occurrence of maintenance activity which leads to the identification by system components of cost, man-hours, parts cost, and occurrence rates. An exception reporting system identifies the top contributors to unsatisfactory performance for each major system.

The cognizant system manager reviews these reports and if he deems items appearing in the reports sufficiently bad, he may institute corrective actions.

The maintenance data collected are also available as an aid to establishing requirements for new similar systems. With additional data processing, the services also use these data to revise and update their prediction handbook (MIL-HDBK-217) and data banks, such as RAC and FARADA.

3. APPLICABILITY OF DOD METHODS TO THE ELECTRIC POWER INDUSTRY

3.1 Acquisition Concepts

3.1.1 Reliability-Maintainability Program

The DoD requires that an organized reliability and maintainability effort be defined. Program elements have included activities such as:

- Management and control
- Subcontractor and supplier program
- Program review
- Design analysis
- Reliability analysis
- Parts reliability
- Failure modes and effects analysis
- Critical item control
- Storage and handling impact analysis
- Design review

The DoD is reemphasizing the design-related activities within the program. The concept of test-analyze-fix during the design-development phase is being stressed as an approach which produces true reliability and maintainability growth.

The electric power industry could benefit from an organized program of design-related activities directed toward assessing the capability of systems to operate satisfactorily in their intended environments for desired periods of time imposed by prescribed maintenance expenditure. Each system acquisition is different and presents differing risks and uncertainties; therefore, it is necessary to define a general approach which may be tailored to fit each specific situation.

It is important that the system reliability and maintainability operational requirements be quantitatively identified, allocated to subsystems, and tracked throughout development, production, and operation. The inclusion of performance assurance parameters as contractual requirements is desirable, but the requirement to demonstrate compliance must be practical.

Reliability demonstration using statistical plans* such as those called for in MIL-STD-781 for system acquisition can be very costly, especially for low production items with moderate MTBF (100 hours). The DoD has

*A statistical test plan involves the use of mathematical statistics to calculate how long the system must function without failure in order to meet a quantitative goal (e.g., MTBF) at a specified level of confidence. Typically, the system must operate without failure for a period substantially longer then the MTBF goal in order to pass the test.

substituted, in some cases, a limited failure-free operation test (burn-in) in lieu of the formal test. Also, it has used warranty as an alternative to demonstration test, relying on incentive (positive and negative) for reliability achievement. It would appear that the power industry could also make use of a similar policy.

Maintainability demonstration is not nearly as costly as reliability. However, in many situations it is viewed as a less critical system parameter and the developing agency may choose not to employ demonstration. It is recommended that the electric power industry review the value of maintainability verification and determine its applicability on a case-by-case basis.

3.1.2 Standards

Although conclusive evidence is not readily available, the DoD appears to have experienced its greatest success with standardization at the equipment and part-component levels. Standardization above these levels seems to become technically obsolete rapidly and is complex to administer. The electric power industry could benefit from the development of recommended standards if the appropriate levels can be defined.

3.1.3 Test Programs

Tests in simulated operating environments form a vital part of the DoD approach which is receiving greater emphasis. To meet these test requirements, the DoD has developed specialized facilities. The possibility of developing similar facilities and an appropriate organizational structure should be studied for application in the electric power industry.

3.2 Operational Assessment

The DoD has structured maintenance management data systems, within the several services, to help collect and analyze field performance data.

The development of a comparable data-gathering and feedback system should form a vital part of the electric power performance assurance program. The aim should be to enhance existing data bases and establish an on-going operational assessment program which can identify problems with existing systems and provide data for defining future requirements.

4. DESCRIPTION OF APPLICABLE PRACTICES

Highlights of the applicable acquisition practices and operational assessment methods are reviewed in this section. Also, some of the changing trends emerging within the DoD approach to performance assurance are noted.

4.1 Current Acquisition Concepts

Currently, DoD treats reliability and maintainability as quantitative parameters specified as part of the development and production contract. A series of handbooks and standards have been developed to provide the mechanism for this process. Table A-1 describes the essential elements of these major DoD documents.

4.1.1 Test and Demonstration

It should be noted that the documents put major emphasis on requiring the contractor to perform special tasks as part of his development effort and then to demonstrate that his product has met any established contractual reliability and maintainability requirements by performing a demonstration test. Such tests may be applied as part of engineering development as well as continuing production demonstration. Due to the high cost of demonstration programs, a number of recent DoD programs have made use of burn-in programs* in lieu of formal demonstration.

4.1.2 Parts Control

Another part of the DoD program for reliability achievement is directed toward parts selection and control. MIL-STD-609, Failure Rate Sampling Plan and Procedure, is used to evaluate the failure rate of parts. MIL-STD-790, entitled "Reliability Assurance Program for Electronic Parts Specification" details actions needed to assure reliability achievement in component parts. Additionally, the Defense Electronic Supply Center (DESC) maintains a stock of selected standard parts which may be acquired by vendors for construction of DoD systems.

4.1.3 Quality Conformance

Table A-2 highlights some of the major quality specifications now being used to assure conformance to specification. These include the sampling inspection procedures, environmental test methods, and quality control program requirements.

The DoD also maintains a wide range of specifications and standards on related topics such as system safety, configuration control, etc., to guide the system developer. Recently within the DoD, some individuals have expressed the opinion that too many specifications are being used, leading to over-control of the design and production process; an effort is being made to liberalize quality control requirements.

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*A burn-in program typically requires that the equipment operate failure-free for some period ranging between 25 and 100 hours, a value generally much less than the expected MTBF. If the equipment fails, the equipment is repaired and the test is repeated until it achieves the required failure-free operation.

Table A-1. DOD RELIABILITY AND MAINTAINABILITY SPECIFICATIONS		
Reference	Title	Essential Elements
MIL-HDBK-217B	Reliability Prediction of Electronic Equipment	Provides standard methods for performing parts-stress and parts-count prediction along with supporting data for a wide range of commonly used electronic and electromechanical parts. These techniques are applicable during system design prior to equipment fabrication and test.
MIL-STD-470	Maintainability Program Requirements	Defines the maintainability program requirements to be accomplished by the system contractor, including activities such as (1) program plan, (2) maintenance concept, (3) design criteria, (4) design trade-off, (5) vendor control, (6) program integration, (7) design review, (8) data collection, (9) demonstration test, and (10) program reporting.
MIL-STD-471A	Maintainability Verification, Demonstration, or Evaluation	Establishes uniform test methods and procedures for assessing system maintainability parameters such as maintenance manhours, and mean, median, and critical percentile downtime.
MIL-HDBK-472	Maintainability Prediction	Provides four techniques to estimate the expected maintainability characteristics of a system during the design phase. The technique includes: (1) a system time element synthesis technique, (2) a part-time element synthesis technique, (3) a task assessment technique which relates task characteristics to maintenance time, (4) a maintenance time combination model.
MIL-STD-690B	Failure Rate Sampling Plans and Procedures	Provides procedures for failure rate qualification, and a sampling plan based on exponential distributions.
MIL-STD-721B	Definition of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety	Contains the definitions of parameters and terms used in performance assurance.
MIL-STD-756A	Reliability Prediction	Establishes uniform procedure for predicting the quantitative reliability of DoD systems. Provides gross active-element-prediction procedure and cites techniques in MIL-HDBK-217 for detailed analysis.
MIL-STD-757	Reliability Evaluation from Demonstration Data	Provides uniform procedures for evaluating achieved reliability and details the need for reliability block diagram, mission evaluation, reliability calculations, etc.
MIL-STD-781B	Reliability Tests: Exponential Distribution	Outlines test levels and test plan for reliability qualification (demonstration), production acceptance, and for longevity tests. The test plans are applicable to systems for which failure patterns follow the exponential or Poisson distribution. These tests do not replace design, performance, environmental, or other design-development tests.
MIL-STD-785	Reliability Programs for Systems and Equipment Development and Production	This standard establishes the criteria for the preparation and implementation of a reliability program plan by system contractors. Key elements of the program requirements include: (1) reliability organization, (2) program interface with other performance activities, (3) supplier control program, (4) program review, (5) design analysis, (6) reliability analysis, (7) parts reliability, (8) failure mode and effects analysis, (9) critical item control, (10) design review, (11) test plan, (12) development testing, (13) demonstration testing, (14) failure data, (15) production reliability control, (16) reprocurement control, and (17) reporting.

Table A-2. MAJOR DOD QUALITY SPECIFICATIONS		
Reference	Title	Essential Elements
MIL-STD-105	Sampling Procedure and Tables for Inspection by Attributes	Establishes sampling plans and procedures for inspection by attributes, by which the unit of production is classified simply as defective or non-defective by some established criteria.
MIL-STD-810C	Environmental Test Methods	Establishes uniform environmental test methods for determining the resistance of equipment to the effects of natural and induced environments. The document describes test conditions, test procedures, test facilities and apparatus, test sequence, and detailed test methods.
MIL-Q-9858	Quality Program Requirements	Sets forth the requirements for a system supplier's quality control program. Major elements include: (1) Organization (2) Quality planning (3) Work instruction (4) Records (5) Corrective action (6) Cost related to quality (7) Drawing, documentation, and changes (8) Measuring and test equipment (9) Production testing (10) Inspection equipment (11) Metrology requirement (12) Control of purchase (13) Manufacturer control (14) Contractor-government coordination

4.1.4 Warranty

On a limited basis, some procurements have made use of reliability improvement warranties (RIW). The RIW is a long-term agreement (3-5 years) requiring the contractor to repair all items which fail during the period under a firm fixed-price contract. Any action which the contractor can take to either reduce the number of failures or lower the time to repair will increase his profit margin, motivating him to improve the equipment by building in reliability during design and through the development and implementation of "no-cost" (to the government) engineering changes. Preliminary results indicate the RIW concept to be effective.

4.2 Operational Assessment

Complementary to the acquisition control techniques, the DoD has requirements for operational test and evaluation of newly developed systems prior to wide-scale deployment. DoD Directive 5000.3, Test and Evaluation, (Key Document A-5) sets forth the general policy for such testing. These tests are made by the services' own people to ascertain suitability of the system to the full service environment. The services maintain test groups separate from the development agency to provide an unbiased assessment. Although the groups gather some numerical data, their tests are generally more qualitative than quantitative.

After field deployment of the system, the services collect failure and maintenance data, e.g., Air Force AFM-66-1, Navy 3M. These data are analyzed by cognizant service engineering groups. If repetitive failure patterns are observed, action is taken to identify the cause and to establish corrective actions, leading to modification of the field units if warranted. If the item is still in production, the action will be coordinated with the developing agency, which will in turn advise the contractor to modify his production units.

Field performance data are also used to establish the reliability and maintainability goals or requirements for future system developments.

4.3 Developing Trends

As noted, the emphasis within the DoD is changing from a total demand for technical performance to a better balance between technical performance and cost. Some reliability assurance efforts tended to emphasize organization structure, documentation, and analysis judged to have little or no effect on designs. Expensive demonstration tests were often performed so late that they had little opportunity to affect design. This has led to a reexamination of the methods used and their effect on the product's reliability and maintainability.

As part of this new trend the Naval Material Command has outlined the following new policy:

Objectives

- Improve fleet readiness
- Minimize life-cycle cost

Acquisition Fundamentals

- Contract for reliability
  - Requirements not goals (requirements may be nonquantitative)
  - Incentives for reliable design
  - Reliability in source selection
  - Life-cycle cost consideration
- Design to minimize failure
  - Mission and environmental profiles
  - Design alternatives studies
  - Numerical allocation
  - Conservative derating criteria
  - Stress analysis
  - Sneak-circuit analysis*
  - Worst-case tolerance analysis
  - Failure modes and effects analysis
  - Parts and materials selection and screening
  - Design reviews
- Integrate testing to verify design
  - Mission profile development test (TAAF)
  - Design limit qualification test
  - Mission profile demonstration test
  - Failure-free random vibration acceptance (electronics)
  - Failure-free all equipment screening

*An analysis of interactions between components, modules, and subsystems.

- Prevent failure recurrence
  - Failure reporting
  - Failure analysis
  - Corrective action
- Sustain reliability in production
  - Quality assurance
  - Process controls
  - Acceptance testing and inspection
- Sustain reliability in service use
  - Initial fleet tracking
  - Contractor corrective action responsibility

Impact

- Reduce maintenance and support burden
- Increase certainty of reliable material acquisition
- Strengthen Navy-contractor technical team

This concept is documented in the Naval Material Command's directive NAVMATINST 3000.1A.

The DoD is in the process of issuing a comparable document emphasizing reliability design analysis and development testing to achieve reliability growth* during the development process. More emphasis will be placed on assessment than on demonstration to prescribed levels of producer and consumer risks. It is expected that broader use will be made of warranties as an adjunct to the performance assurance program as a means of motivating the contractor to achieve reliability and maintainability growth.

Also pending within the DoD are specifications addressing reliability assurance as it relates to computer software and human factors.

4.4 Lead Responsibility and Interfaces

The overall policy and procedures are established at the DoD level. Each service may use the procedures directly as in the case of MIL-STDs or develop implementing procedures as in the case of directives, e.g., DoD Directives 5000.1 and 5000.2. These instructions flow down separately

*Reliability growth refers to the rate at which reliability improves. A considerable body of literature has reported ways to increase this rate.

through the various organizational channels, i.e., system acquisition command, operations, and logistics activities. Within each of these activities the procedures are invoked as required in the acquisition, operation, and support of systems.

The key interfaces are between the DoD elements and their major contractors and suppliers. The wide range of DoD specifications define the nature of this interface. Within the government, the DoD has limited interface with other government agencies with common points of interest on selected systems, e.g., FAA, NASA, UMTA.

5. PROGRAM COST AND EFFECTIVENESS

5.1 Program Cost

The added cost of DoD performance assurance activities is difficult to determine due to its close association with normal engineering and test activities, but several studies have attempted to show the cost-effectiveness of these activities. Although the results of the studies supported the use of performance assurance, the limited scope of the investigations prevent them from being conclusive. DoD argues that without these efforts complex systems would have insufficient reliability to meet mission requirements. The effect of reliability on system life-cycle cost can be clearly shown; the analysis indicates it to be, in many cases, a major cost driver which must be controlled. The missing element preventing a true effectiveness assessment is the total cost of the assurance program.

DoD equipment suppliers estimate that a full application of MIL-STD-781,-785,-470, and -471 could add 10 percent to the cost of a prototype system. More common actual expenditures would probably be on the order of 1 to 3 percent. It is important to note that these development costs can be small for each unit if they are spread across a large production base. Use of high-reliability parts can further increase both development and production costs.

The cost of a full MIL specification program is not known. One manufacturer who built similar products for both DoD and industry estimated that the DoD methods added 60 percent to the production cost of the DoD item over that of the unit manufactured to commercial specifications. He also stated that the quality and reliability of the commercial product equaled or exceeded that of the military product. The aviation community requires good quality, but is less demanding in regards to design details and associated documentation.

5.2 Program Effectiveness

Overall, the DoD performance assurance program has to be classed as a success. The program has produced weapon systems with acceptable reliability and maintainability levels. Had the failure rates experienced by DoD systems during the early 1950s continued, the highly sophisticated weapon systems

now being used would be totally impractical. Programs which place emphasis on a clear statement of system requirements and follow with comprehensive design analysis and testing appear to be the most effective in improving the availability, reliability, and maintainability of DoD systems.

APPENDIX B

PERFORMANCE ASSURANCE AS PRACTICED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

1. HISTORICAL DEVELOPMENT AND TRENDS

The NASA performance assurance program, consisting of two components, quality assurance and reliability assurance, evolved directly from DoD practices of about 1959-63.

The period from 1952 to the early 1960s was characterized by rapid technological change and attempts by the military to realize the benefits of a vast array of promising new technological developments as fast as possible. The size, complexity, specialization, and scope-of-deployment of aerospace systems increased rapidly during this era, thereby stimulating an ever-increasing emphasis on reliability assurance to overcome the low reliability of these new systems. As General Simon* points out, the distinction between reliability, R, and very high reliability (VFR) was not an important distinction at that time because the reliability was so low. Most programs were geared to achieving comparatively low reliability goals, low enough to allow the application of rigorous sampling, testing, and operational verification techniques. Thus, this era was characterized by the rapid development of quantitative methods for predicting, testing, and demonstration reliability. By 1964 approximately 30 to 43 percent of government contracts contained quantitative reliability requirements.**

The NASA era began in the early 1960s with the conversion of military guided-missile technology to space exploration requirements. Initially, NASA also adopted military reliability and quality assurance programs. However, it soon became apparent that NASA would have to devise its own reliability and quality assurance program in order to assure the very high system reliability required to accomplish its primary mission. This mission was to land men on the moon under the watchful eye of many millions of televiewers and assure that the risk to astronauts would be "no greater than that accepted by an average man pursuing his normal, daily activities".

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*L. E. Simon, "The Relation of Engineering to Very High Reliability", *Proceedings - Tenth National Symposium on Reliability and Quality Control*, 1964, pp 226.

**E. F. Dertinger, "Status of Reliability Requirements in Government Contracts", *Proceedings - Eleventh National Symposium on Reliability and Quality Control*, 1965.

Therefore, it became necessary to develop performance assurance programs and techniques which did not depend upon statistical validation. In essence, NASA developed approaches aimed at discovering and correcting failure mechanisms throughout the entire system acquisition phase. NASA placed unprecedented emphasis on reliability analysis during the design state, integrated environmental testing and test-to-failure of components during the development stage, and system checkout before launch.

2. SCOPE OF NASA PERFORMANCE ASSURANCE PRACTICES

NASA's approach to performance assurance involves: (1) an extensive in-house effort which precedes the acquisition of any system or major subsystem, (2) contractor's reliability and quality programs, (3) continuous review of contractor's programs throughout the acquisition process, and (4) careful monitoring of system performance during operation. The approach is applied to launch vehicles and spacecraft.

The preliminary in-house effort involves three levels of activity -- a feasibility study, mission planning, and acquisition planning.

2.1 Feasibility Study

First, a feasibility study is conducted, similar in scope to that conducted by an electric utility in planning for capacity expansion. During this phase, the reliability requirements and factors are considered relative to those already achieved by comparable systems in operation.

2.2 Mission Planning

Second, the mission and system concepts are refined. During this phase, the reliability and quality program requirements are established. The emphasis on various aspects of reliability and quality assurance are tailored to fit specific mission requirements. Critical mission parameters are identified, analyzed, and documented.

2.3 Acquisition Planning

The third stage in the preliminary in-house effort is the preparation of a procurement plan, the preparation of procurement documents, and the evaluation of proposals and bidders. Because NASA often worked at or just beyond the technical state of the art, considerably more time and effort was spent in specifying and evaluating contractor's reliability and quality assurance programs than in specifying, standardizing, and evaluating technical approaches and hardware. NASA was also very sensitive to past reliability and quality performance by contractors. In most cases, NASA depended upon the services of a prime contractor to work out detailed approaches to meet the reliability goals, to apportion requirements within the system, and to develop and negotiate techniques for reliability assurance at all levels in the system hierarchy.

2.4 Contractor's Reliability and Quality Programs

NASA performance assurance requirements for contractors are summarized in two documents: "Quality Program Provisions for Aeronautical and Space System Contractors" (Key Document B-1), and "Reliability Program Provisions for Aeronautical and Space System Contractors" (Key Document B-2).

2.4.1 Quality Program

The NASA-imposed quality assurance program consists of twelve elements or formalized activities:

- Quality program management and planning
- Design and development controls
- Identification and data retrieval
- Procurement controls
- Fabrication controls
- Inspection and testing
- Nonconforming article and material control
- Metrology controls
- Stamp controls*
- Handling, storage, preservation, marking, labelling, packaging, packing, and shipping
- Sampling plans, statistical planning, and analysis
- Government property control

It is important to recognize that NASA contractors often retain a major role, not only during system acquisition and test, but during flight operations as well. Thus, for example, the system contractor (prime contractor) often addresses quality program requirements as outlined in Table B-1.

2.4.2 Reliability Program

The NASA-imposed reliability program consists of twenty elements or formalized activities in three categories:

- Reliability Program Management
  - Organization
  - Reliability program plan
  - Reliability program control
  - Reliability progress reporting

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*Approval is often signified by a stamp. Access to these stamps is tightly controlled.

Table B-1. QUALITY PROGRAM REQUIREMENTS	
Stage	Contractor Responsibility
Design and development	Quality program plan Quality criteria
Purchasing	Purchase-documents control Source inspection Material receipt Process control and inspection Qualification and conformance tests
Fabrication	Process control and inspection Qualification and conformance tests
System assembly	End-item testing
Flight operations	Data collection Data analysis Data feedback

- Reliability training
- Supplier control
- Reliability of government furnished property

• Reliability Engineering

- Design specifications
- Reliability prediction
- Failure mode, effect, and criticality analysis
- Maintainability of the system and elimination of human-induced failure
- Design review program
- Problem and failure reporting and collection
- Standardization of design practices
- Parts and materials program

• Testing and Reliability Evaluation

- Reliability evaluation plan

•• Testing

•• Reliability assessment

Here again, the NASA system contractor (prime contractor) often retains a major role throughout the entire mission.

2.5 Continuous Review During Acquisition and Monitoring of System Performance

NASA's practice of establishing and maintaining a close relationship with the prime acquisition contractor during system operation, coupled with its imposition of operations requirements within the scope of the system contractor's quality and reliability program, lead the acquisition contractor to have a continuing stake in the operational success of the system. (This stake is often made explicit through the use of incentive contracts*.) In practice, this approach to performance assurance leads system suppliers to take considerable interest in continuous review and monitoring throughout the entire life of the system.

As a result, many contractors develop and maintain their own extensive failure reporting and follow-up systems**, often used in pre-launch† and post-launch†† mission analyses. Acquisition contractors also participate in diagnosing and recommending repair actions during launch and in-space operations.#

3. APPLICABILITY OF NASA METHODS TO THE ELECTRIC POWER INDUSTRY

Two important and interdependent aspects of the NASA approach to performance assurance are worth considering for application by the electric power industry. One is NASA's emphasis on establishing detailed requirements and plans for continual and graduated testing throughout all phases of the system acquisition process. The other is NASA's emphasis on understanding and simulating the operational environment during tests. NASA also places considerable emphasis on reliability assurance during the design phase. This emphasis and the associated approach are similar to those described as DoD practice (Appendix A).

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*A. J. Moskovitz, "NASA's Application of NPC 250-1 in Incentive Contracts", *Proceedings - Eleventh National Symposium on Reliability and Quality Control*, 1965.

**E.g., see G. S. Gordon, "Failure Reporting on Satellite Programs", *Proceedings - 1967 Annual Symposium on Reliability*, pp. 128.

†E.g., F. P. Klefer, *et al*, "Man-Rating the Gemini Launch Vehicle", *Proceedings - 1966 Annual Symposium on Reliability*, pp 260.

††E.g., B. B. Klawans and E. C. Thomas, "Flight Performance Analysis of Space Systems", *Proceedings - 1969 Annual Symposium on Reliability*.

#E.g., W. R. Abbott and L. E. Jenkins, "Flight Failure Analysis", *Proceedings - 1969 Annual Symposium on Reliability*, pp 244.

3.1 Test Requirements and Plans

NASA typically devoted a considerable effort to develop mission effectiveness criteria and system availability requirements during the pre-acquisition phase. Experience from previous flights and tests was incorporated to identify critical problems so that contractors could work out and negotiate test requirements and testing plans at appropriate levels of test emphasis.

Electric power utilities could benefit from NASA's experience by placing more emphasis on establishing graduated test requirements during the planning phase and by formulating test plans in cooperation with their contractors. A mechanism could be developed to make available these test plans and subsequent evaluations of test results to all companies.

3.2 Simulating the Operational Environment

NASA places great emphasis on testing in an environment approximating operational conditions. NASA centers and contractors employ specialized teams to analyze and understand the operational environment to design appropriate environmental simulations and to evaluate the effect of environmental stress and peculiarities.

Electric utilities and their contractors would benefit from the preparation of environmental simulation guidelines. Further, it may be appropriate to consider establishing national environmental testing facilities and specialized support staffs.

4. DESCRIPTION OF APPLICABLE PRACTICES

The NASA approach to performance assurance allows enormous flexibility. Each prime contractor negotiates a performance assurance program in cooperation with the NASA Center in charge of the program, within the guidelines specified in Key Documents B-1 and B-2. Therefore, rather than describe a specific NASA program in order to convey the essence of NASA's approach to performance assurance, we have chosen to describe a "prototypical" NASA performance assurance program drawn from actual programs that have been documented in the most detail. In constructing this prototypical program we have tried to emphasize those elements most peculiar to NASA that also seem most applicable for consideration by the power industry.

4.1 Key Program Elements

4.1.1 Spacecraft Mission Effectiveness Analysis (SMEA)

NASA's emphasis on graduated testing in simulated or actual mission environment led to a philosophy of treating each space mission as a test for the next. NASA utilizes the SMEA to establish explicit and quantitative *a priori* measures of achievement during the planning stage and to express these measures relative to *a posteriori* evaluations of achievement by

systems already in operation. As used in the orbiting geophysical observatory (OGO) program by NASA*, the achievements expected of one of the series of "standard" satellites were expressed relative to the achievements of others in the same series already in operation. In the case of OGO, the effectiveness was defined by an independent** contractor (Planning Research Corporation) in cooperation with the ultimate user (NASA) and the system acquisition contractor (TRW). One result was the definition of an overall figure of merit for the system, used throughout the development of the OGO series to postulate and evaluate improvement in mission performance.†

4.1.2 Launch Availability Analysis

As utilized by NASA, availability analysis is performed throughout the entire life cycle of the system from concept through operation.

As applied on Saturn V††, the analysis involved a large-scale digital computer simulation model that analyzed and simulated the performance of the system during all operations up to launch. This model utilized system reliability data, maintainability data, and operating time constraints to determine the probable Saturn V system availability at launch time.

The failure rate methodology involves the transition from predictive data to assessment data, combining failure rate predictions with field failure data through the use of both classical and Bayesian techniques. The model programs approximately 2000 equipment categories used in over 200 operational events leading up to the Saturn V liftoff. The data bank stores generic failure rates, maintenance times, environmental factors, stress levels, and operating times for the major components, subsystems, and systems within each individual pre-launch event.

4.1.3 Flight and Test Performance Analysis

NASA performance analysis includes preparation, implementation, and communication phases. The formal performance analysis described below was developed for application to the Nimbus Meteorological Satellites, the Applications Technology Satellites, the Geophysical Earth Orbiting Satellites, and the biosatellite and several military systems (the description is taken from the previously cited paper by Klawans and Thomas).

During preparation, the scope of the test performance analysis is projected in terms of magnitude, schedule, interfaces, and cost. Flight and test performance analysts are assigned to particular subsystems and trained for the analysis ahead.

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*A. Leventhal and C. E. Bloomquist, "Spacecraft Mission Effectiveness", *Proceedings - 1968 Annual Symposium on Reliability*, pp 615.

**Independent contractors do not subcontract to acquisition contractors but work directly for the purchasing agency.

†A. Leventhal *et al*, "Spacecraft Failure Rates -- Where Are We?", *Proceedings - 1969 Annual Symposium on Reliability*, pp 444.

††R. A. Venditti and R. M. Sineath, Jr., "Saturn V System Reliability Analysis", *Proceedings - 1969 Annual Symposium on Reliability*, pp 567.

The implementation phase has two segments. The first segment is an in-depth analysis of anomalous performance of spacecraft during flight or test to isolate the cause of a failure to the piece-part level and determine the extent of its effect on the mission. The second segment is a total system capability determination initiated during system development tests and continually updated through qualification, acceptance, and flight testing. Information is gathered continually to define the adequacy of the system test requirements and the total performance envelope that is available with maximum utilization of the present design and to identify those changes that may be incorporated to improve performance.

Most contractors use the flight and test performance analysis team concept to communicate the results of the team effort; frequent working-level briefings are held for all evaluation personnel. In general, the company position on each observed anomaly is stated in a scheduled letter report to NASA. This letter is followed by an in-depth analysis report giving detailed information on all anomalies. The flight and test performance analysis group also prepares the *On-Orbit User's Handbook* which contains systems specifications, systems performance during acceptance testing and launch preparation, normal transient signatures of the actual hardware being flown, and overall system test results. For some programs a computer tape is prepared in addition to the on-orbit handbook so the prior performance may be displayed automatically and compared to current performance.

The functionally organized flight-performance analysis team provides a degree of cross-fertilization that is difficult to obtain within a totally project-oriented program. A failure is not dismissed when the immediate problem has been resolved. Its impact on every current and anticipated program is evaluated and corrective action is taken across the board to prevent recurrence.

4.1.4 Defining Reliability Test and Demonstration Requirements

As R. B. Carpenter points out*, requirements for reliability have been increasing by several orders of magnitude for each generation system, while the ability to demonstrate reliability performance has shown a corresponding decrease. If the system to be demonstrated actually has the very high reliability required by NASA, the time required for statistically valid tests at the system level usually exceeds the time available for the whole program. Hence, NASA programs rarely require statistical validation at the system level. Instead, a series of integrated tests, combined with analysis, are performed as the system is designed and developed. The result is an engineering confidence level not definable in statistical terms.

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*R. B. Carpenter, Jr., "Demonstrating Reliability for Long Space Missions", *Proceedings - Eleventh National Symposium on Reliability and Quality Control*, 1965, pp 223.

Optimizing the test and demonstration program is a crucial part of NASA's performance assurance programs. A typical approach, described by Carpenter as being used by North American Aviation is based on the application of two independent analyses -- pretest analysis and test emphasis analysis. These analyses, used in conjunction with a formal "needs" analysis, provide assurance of design integrity, even though statistical confidence is often lacking.

The needs analysis, aimed at defining the types of tests required to evaluate performance of the system, may be similar to those already described under the headings of spacecraft mission effectiveness analysis, availability analysis, or flight and test performance analysis. Carpenter suggests that needs analysis should be a sequential composite of the three analyses.

The test emphasis analysis (TEA) determines the number and duration of tests required for individual constituents of the system. A test emphasis index is established to determine the sample size and test duration for each system, component, and part. Also, TEA may be used to establish the percent of the budget to be apportioned to various levels as a function of overall cost or schedule. The purpose is not to demonstrate performance with mathematical rigor but to budget test effort within the practical constraints imposed at each stage in the acquisition process.

4.1.5 Design Proof Tests*

The design proof tests used on Apollo followed MIL-E-5272 except that environments were at the anticipated maximum level of stress for a typical Apollo mission. Each environment was applied at the component level in sequence and in ascending order of severity to verify ability to perform under single worst-case conditions. Test safety margins were set at about 1.33 times the anticipated level in more than 90 percent of the possible situations. Test safety margins were set somewhere between the level of the designer's margin and the normally anticipated level.

4.1.6 Off-Limit Tests

In the off-limit tests (described by Carpenter) a given stress is increased in small increments until failure occurs or until the design margin is exceeded substantially. The purpose of these tests is to supplement other test data, determine comparative reliability between component types, increase the effective sample size for increased statistical confidence, and provide a basis for trade-off analyses.

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*R. B. Carpenter, Jr., "Apollo Reliability by Demonstration or Assessment", *Proceedings - Tenth National Symposium on Reliability and Quality Control,* 1964, pp 517.

4.1.7 Mission Simulation Life Tests

For application to Apollo, Carpenter reported that four simulated "mission cycles" were imposed on each system designated for the test. The mission simulation includes all passive and active states as well as passive and active environments, both singly and in combinations. Two cycles per system had to be accomplished without a failure for successful completion of the test series.

4.1.8 Acceptance

NASA's decision to buy or not to buy was not made on the basis of any single test, but involved an evaluation of all tests required during design, pre-production, production, and post-production phases. For example*, in accepting launch vehicles, NASA required successful completion of initial acceptance tests (laboratory static bench-test), pre-production tests in appropriate environments, production acceptance tests applied at end-use operating environmental stress levels, periodic reevaluation tests of questionable items in adverse environments, off-limit tests, and extended time tests.

4.1.9 Lead Responsibilities

NASA Headquarters has lead responsibility for preparing and updating general performance assurance guidelines. These are implemented by the NASA centers, to the extent that each center finds them pertinent. NASA Headquarters reviews the center programs annually and submits recommendations for improvement. Although the centers delegate considerable responsibility to integration contractors and prime contractors, center personnel retain responsibility for accepting or rejecting test plans and results.

4.1.10 Government-Industry Interface

Because NASA funds the aerospace industry directly, the government-industry interface is a contractual one. It is important to NASA that the contractual relationship with contractors employed during the system acquisition stage be maintained during system operations.

5. COST AND EFFECTIVENESS CONSIDERATIONS

NASA estimates that the average cost of applying formal performance assurance to all launch vehicles and spacecraft during the 1960s was 10 percent of the system acquisition cost.

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*C. C. Campbell, "High Reliability for Space Launch Vehicles", *Proceedings - Eleventh National Symposium on Reliability and Quality Control*, 1965, pp 439.

5.1 Program Initiation Costs

Initiation costs were predominantly those associated with the development and installation of major test and mission simulation facilities. A considerable portion (10 to 20 percent) of NASA's total budget ($3 - $5 billion per year) was allocated to the installation of these facilities during the first five years of NASA's history.

5.2 Program Operating Costs

The cost of operating the performance assurance program in its mature state (about 1965) was reduced substantially as launch vehicles, spacecraft, and procedures became more standardized.

5.3 Program Effectiveness

The early NASA missions suffered from poor system reliability, evidenced by numerous flight delays and aborted missions. As emphasis was placed on performance assurance, the mission success rate improved. NASA's basic approach of identifying mission environmental requirements and employing exhaustive testing against these requirements has led to excellent system reliability. The recent Mars landing with the Viking spacecraft is a clear indication of this achievement.

APPENDIX C

PERFORMANCE ASSURANCE AS PRACTICED BY THE FEDERAL AVIATION ADMINISTRATION AND AIRLINE INDUSTRY

1. HISTORICAL DEVELOPMENT

The Federal Aviation Administration (FAA) now resides within the Department of Transportation, having at one time been an independent agency. Performance assurance has long been a key part of FAA's concern, particularly as it relates to airworthiness, quality, and safety.

Following DoD's lead in the development of complex systems, the air transport industry made use of many of the military-developed systems (e.g., aircraft, radar, navigation, communication) and experienced similar reliability problems. One of the earliest reliability studies was triggered by the unacceptable reliability of an airborne communications transceiver in use by the commercial airlines. The work on this problem performed by Aeronautical Radio, Inc., (ARINC) led to the development of a line of "high reliability" vacuum tubes for use in the equipment. The success of the program led to ARINC's being requested to initiate similar efforts for the military in 1951 -- one of DoD's earliest attacks on the reliability problem.

Through the years, the FAA has placed heavy emphasis on qualification testing. However, following the lead of DoD and NASA, the agency has expanded the scope of its reliability and maintainability programs, making use of specifications and procedures developed by other agencies as appropriate.

2. SCOPE OF CURRENT PRACTICES

The FAA activities related to performance assurance are quite broad but for discussion purposes may be categorized to fall within the major areas of aircraft certification, system acquisition and operation, and safety programs.

2.1 Aircraft Certification

FAA ensures that new aircraft, engines and propellers, and the component, parts, and appliances that go with them, are of acceptable quality when completed, by requiring that they be type-certificated. The agency issues type certificates for new models of aircraft, engines, and propellers when they meet prescribed airworthiness and noise standards and are deemed safe. In case of an approved change in a type-certificated model, FAA

issues a supplementary type certificate, or, if the change is substantial enough to warrant it, a new type certificate. Foreign aircraft seeking U.S. certification are subject to standards comparable to those required to be met by U.S. aircraft.

2.2 System Acquisition and Operation

FAA is responsible for the National Airways System, a complex of air traffic control, navigation, and communications systems used to monitor and control air movements through the system. FAA is responsible for the design, acquisition, installation, and operation of all facets of the system. To meet its responsibility the administration has developed a series of performance assurance techniques to control this activity.

2.3 Safety Programs

The FAA also has a broad spectrum of safety program activities, specifically including:

- Aircraft Accident and Notification, Investigation and Reporting
- School and Repair Station Certification
- Airport Certification
- The Mechanic Safety Programs
- The Service Difficulty Program
- The Biennial Airworthiness Review Program
- The Biennial Operations Review Program
- Flight Inspection

3. APPLICABILITY OF FAA METHODS TO THE ELECTRIC POWER INDUSTRY

3.1 System Acquisition and Operation Techniques

The system acquisition and operation techniques employed by the FAA to a large extent are patterned after those of the DoD and NASA. In fact, FAA has used many of the actual DoD specifications and procedures.

3.2 Certification Programs

The FAA certification program governing equipment owned and operated by the air carriers is somewhat analogous to the Nuclear Regulatory Commission (NRC) licensing process. There are several techniques within this program fostered by the FAA and the airline community worth further examination. These include (1) functional standards and (2) the maintenance reliability program.

3.2.1 Form, Fit, and Function Standards

For selected components, the airline community develops functional standards which provide electrical, mechanical, and functional interchangeability among suppliers. In addition to providing a desirable competitive environment for the user, the concept has resulted in highly reliable system components. Through the standards program, a particular subsystem built to the functional specifications prescribed by the airline community will be used in most air carrier aircraft and may be used in many general aviation aircraft. This broad production base, which may be shared by several vendors, permits the designs to mature, leading to the high reliability cited. Competition and use of warranties provide further mechanisms for product quality improvement. The FAA enters into the process by its imposition of certification requirements on top of the basic functional requirements. It would appear that the specification of form, fit, and function would have direct applicability to the electric power industry for many common items used in power generation.

3.2.2 Operational Maintenance Reliability Program

As an extension of its certification process, the FAA requires the airlines to comply with established maintenance and inspection programs. To do so, the airlines have developed a flexible maintenance approach coupled with a tight reliability control program that monitors the failure performance of critical aircraft components in response to changes in maintenance policies. The establishment of a comparable program within the electric power systems for critical systems could prove to be highly cost-effective while providing the needed control of operational systems.

3.2.3 Safety Programs

The safety programs developed by the FAA fit the unique operational requirements of its area of responsibility. They have limited application in the power industry, which has already placed considerable emphasis on safety.

4. DESCRIPTION OF APPLICABLE PRACTICES

The FAA's certification programs and acquisition concepts merit further discussion. Within the certification program the airline procurement concepts and operational assessment procedures are of particular interest.

4.1 Certification Program

4.1.1 System Acquisition

As a partial result of the FAA responsibilities for certificating the quality and airworthiness of systems acquired by the aviation industry, a unique procurement concept has been developed within the airline community.

4.1.1.1 Airline Procurement History and Evolution

The airline procurement process has developed through a number of evolutionary steps. Beginning in the late 1930s, the airlines centralized the preparation of avionic equipment specifications and procurements in a single organization, ARINC. It was believed that if ARINC could coordinate the development activities and equipment needs, standardization would be achieved and significant savings realized.

During the 1940s, the development of specifications and procurement techniques took a significant turn. The preparation of specifications was centered in a specific group of airline people, known today as the Airlines Electronic Engineering Committee, rather than left to whoever attended the general industry meetings of ARINC.

Another turning point in the evolution occurred in the early 1950s, when the writing of ARINC Characteristics became a public process with the participation of manufacturers. Interchangeability was established as the first-priority item, and this became the major purpose of ARINC Characteristics. The premise was that "form, fit, and function" should be a basic standard and that extra operational performance, special features, and flexibility should rightfully remain optional items, to be purchased by those who needed and could afford them.

4.1.1.2 Airline Procurement Participants

The commercial airline procurement method involves the customer (airline companies), the supplier (equipment vendors), and several organizations unique to the United States air transport industry. These organizations include the following:

- Airlines Electronic Engineering Committee (AEEC)
- Avionics Maintenance Conference (AMC)
- Radio Technical Commission for Avionics (RTCA)
- Air Transport Association of America (ATA)
- Federal Aviation Administration (FAA)

The membership, key activities, and contributions of each of these organizations are discussed in the following subsections.

Airline Companies. The U.S. air carriers currently comprise eleven trunk, nine local service, and three cargo carriers. These companies own approximately 2,500 aircraft varying from single-engine, piston-powered vehicles to four-engine jets. It has been estimated that the world's airlines spend more than $300 million annually on avionics.

Avionics Vendors. There are approximately 30 U.S. manufacturers of avionics that serve not only the air carriers' fleet of 2,500 aircraft but also general aviation and the military. The present general aviation fleet consists of about 161,500 aircraft and the military approximately 20,000 aircraft.

ARINC. ARINC was organized by the airlines on December 2, 1969, to serve as the single licensee and coordinator of aeronautical radio communications outside the government. The Airlines Electronic Engineering Committee (AEEC) within ARINC is the focal point for common airline avionic acquisition activity.

The primary function of the AEEC is to formulate ARINC Characteristics, form, fit, and function standards for electronic equipment and systems. An ARINC Characteristic has a twofold purpose:

- To communicate to prospective manufacturers of airline electronic equipment the general desires of the airline technical people, coordinated on an industry basis, concerning a particular type of equipment
- To promote maximum possible interchangeability without seriously hampering design initiative

Before they are published, these characteristics are coordinated and approved after sometimes extended discussions among the AEEC participants. The characteristics do not precisely define the contents of the "black box" but describe the signals that enter and leave the box, and the electrical, mechanical, and environmental interfaces.

RTCA. The Radio Technical Commission for Avionics (RTCA) was formed as an association of more than 100 aeronautical organizations of the United States. Its present membership includes all military departments and the Departments of State, Commerce, and Transportation (FAA), the Federal Communications Commission, the National Aeronautics and Space Administration, the Air Transport Association, Aircraft Owners and Pilots Association, Airline Pilots Association, and manufacturing industry organizations. A key RTCA activity is the preparation of documents that provide minimum performance standards (MPS) and test procedures, environmental test procedures, and operational and technical characteristics of aviation electronics and telecommunications. These documents are used to guide the preparation of ARINC Characteristics, are used as guidelines by manufacturers, and often serve as the minimum-performance test criteria of equipment authorized for use on civil aircraft by the FAA through its Technical Standard Order (TSO) authorization process.

ATA. The Air Transport Association of America (ATA) is a cooperative, non-profit trade and service organization of the U.S. scheduled airlines. Through its member airlines, the ATA works to improve airline safety, service, and efficiency. It is currently divided into eight departments, each of which parallels a function of the airlines. ATA activities that directly affect airline procurements are carried out through a system of councils and related committees made up of airline and ATA representatives.

The ATA publishes several documents that significantly affect the airline procurement process. One is the World Airline Suppliers' Guide, which establishes the policies and objectives of the air transport industry with respect to the suppliers' support of the world airlines' fleet. This guide

provides the consensus of the member airlines concerning general terms and agreements, initial provisioning, inventory policies, pricing, value analysis, order administration, packaging and shipping, invoicing warranties, simulators, and manufacturers' technical data.

The ATA also publishes four specifications commonly used by all airlines in their procurement documents to ensure proper support from each supplier of aircraft products:

- ATA Specification No. 100 - Manufacturers' Technical Data
- ATA Specification No. 101 - Ground Equipment Technical Data
- ATA Specification No. 200 - Integrated Data Processing Supply
- ATA Specification No. 300 - Packaging of Airline Supplies

These specifications were developed to provide guidelines to an increasing number of inexperienced suppliers of the airline industry and to permit mutual savings in technical-data preparation, spare-parts provisioning, and packaging.

FAA. The FAA role in the airline acquisition process is to certify the air-worthiness of aircraft and their equipment. Once a manufacturer has completed the design and production of an avionics product (which may be based on an ARINC Characteristic), he must obtain authorization from the Federal Aviation Administration before the product can be used on civil aircraft. The authorization is issued on the basis of the manufacturer's conformance with FAA Regulation, Volume II, Part 37, and the applicable Technical Standard Order (TSO).

Technical Standard Orders contain the minimum performance and quality-control standards for products used on aircraft. The performance standards in each TSO ensure that the product will operate satisfactorily or will fulfill its intended purpose under specified conditions.

Once a TSO has been authorized for a particular equipment, the manufacturer must produce the equipment in accordance with his application, conduct all required tests and inspections, and establish and maintain a quality-control system adequate to ensure that the equipment meets the requirements of the TSO.

4.1.1.3 Summary

The commercial airlines' process for the procurement of avionic and electronic equipment has evolved over the past 35 years. The process involves the highly competitive, open forum participation of several public and private organizations in addition to the user and supplier.

The airline procurement process is relatively simple when contrasted to military processes; it enables the airlines to acquire highly reliable, state-of-the-art electronic systems offering excellent cost benefits. It is the airline's opinion that the method provides them with good value for the dollars expended.

4.1.2 Operational Assessment

As an extension of the certification program for new acquisitions, the FAA maintains an active role in monitoring the failure occurrences rate and maintenance practices of the aviation community. The FAA is also concerned with the field performance of systems it acquires and operates.

4.1.2.1 Reliability-Maintenance Program

For each aircraft type certificated, the FAA establishes a maintenance and inspection program to be followed. The operator must maintain appropriate records to verify that he has been following the procedures established.

Some of the air carriers believed that the program was overly restrictive and that the standards did not always track actual experience. As a result, in cooperation with the FAA, they developed a reliability program which provided the carriers more flexibility while continuing FAA control.* The essence of the concept is that the carrier is permitted to define its own maintenance concept, and may change it as the carrier sees fit. It must, however, maintain a data system which shows at all times that affected systems components are within established failure rate bounds.

The maintenance planning technique used by the airline community, the Airline/Manufacturer Maintenance Program Planning Document, is known as "MSG-2". It entails a systematic review of all possible maintenance tasks in the context of five basic questions.

1. Is reduction in failure resistance detectable by routine flight crew monitoring?
2. Is reduction in failure resistance detectable by in-situ maintenance or unit test?
3. Does the failure mode have a direct adverse effect upon operating safety?
4. Is the function hidden from the view of the flight crew?
5. Is there an adverse relationship between age and reliability?

Each of the questions is asked in isolation from the others. Items which receive yes answers for Questions 3 and 4 are candidates for some type of positive maintenance action. Yes answers for Questions 2 and 5 may be candidates if the maintenance action is determined to be practical.

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*FAA Advisory Circular AC 120-17, "Handbook for Maintenance Control by Reliability Methods", December 1964.

The following three types of positive maintenance actions are recognized:

- Hard Time Tasks (HT) - Item is removed from service at specified intervals.
- On-Condition (OC) - Periodic tests are made to assure item is meeting performance requirement with item being removed from service when found deficient.
- Condition Monitoring (CM) - Item is removed from service when observed to be deficient.

The typical distribution of maintenance actions among these categories for several selected aircraft types are shown in Table C-1.

Table C-1. DISTRIBUTION OF POSITIVE MAINTENANCE ACTIONS

Aircraft	Total Action	Percent		
		HT	OC	CM
DC-9	1260	17	19	64
727	2078	17	25	58
707	3010	18	27	55
L-1011	4539	4	9	87
747	5908	6	22	72

In the newer aircraft designs (L-1011 and 747) significant progress has been made reducing the hard-time and on-condition maintenance requirements. This has been accomplished through better fault monitoring and redundancy.

For a new aircraft, the several airlines buying the aircraft form a team to perform the MSG-2 analysis jointly. The aircraft manufacturer supplies the initial task data the committee uses for its analysis. The FAA is invited to participate since the completed analysis is submitted to the administration for review.

Some airlines do not apply the MSG-2 analysis to structural items although the procedure is designed to cover them. They believe there is insufficient information regarding those items to justify a maintenance program.

A key part of the analysis is setting the intervals between maintenance actions for the HT and OC items. The airlines typically start with intervals that have been used for similar items in existing aircraft. As they gain experience, the intervals are adjusted upward or downward as deemed appropriate.

The DoD has widely used the MSG-2 concept as a tool for planning maintenance on military aircraft.

4.1.2.2 Mechanical Reliability Report

As a further control, the FAA requires Mechanical Reliability Reports (MRRs) from air carriers.

All domestic scheduled air carriers are required to use and implement the MRR system by CFR Title 14, Rule No. 121.703. Each carrier is required to report the occurrence or detection of each failure, malfunction, or defect related to sixteen specific conditions listed in Table C-2. Other conditions may be reported by the carriers.

The main characteristics of the MRR system follow:

- The carrier submits an MRR to the FAA Principal Inspector within 24 hours after the end of the previous 24-hour period in which an event occurred. The carrier uses its own reporting form; one FAA Principal Inspector is assigned to each carrier.
- The Principal Inspector transcribes the data into the FAA MRR system and forwards it to the Maintenance Analysis Center (MAC) within 24 hours.
- Every day, the MAC Data Bank prepares a "Flight Standards Service Difficulty Report" (FSSDR), which tabulates total occurrences entered into the data bank on a specific date.
- After the carrier's report has been reviewed for completeness, it is entered and stored as an open or closed MRR in the MAC Data Bank. The FSSDRs are mailed from MAC within two to three days after receipt of the MRRs from the Principal Inspector.
- The FSSDRs are automatically mailed to all carriers, prime aircraft manufacturers, submanufacturers, and other subscribers to the service.
- Critical occurrences are identified on the FSSDRs by an extra heavy black line border.
- The status of all open items is reported periodically by MAC.
- The carrier is required to submit a follow-up report on open items to the Principal Inspector following the analysis of the problem or occurrence. There may be one or more follow-up reports before the occurrence is closed.

Table C-2. EVENTS REQUIRING AN FAA MECHANICAL RELIABILITY REPORT
Fires during flight and failure of the related fire-warning system
Fires during flight not protected by a related fire-warning system
False fire warnings during flight
Engine exhaust systems that cause damage during flight to an engine, adjacent structure, equipment, or components
Aircraft components that cause accumulation of circulation of smoke, vapor, or toxic or noxious fumes in the crew compartment or passenger cabin during flight
Engine shutdowns during flight because of flameout
Engine shutdowns during flight as a result of external damage to the engine or airplane structure
Engine shutdowns during flight due to foreign object ingestion or icing
Shutdowns during flight of more than one engine
Failure of propeller feathering system or of the ability of the system to control overspeed during flight
A fuel or fuel-dumping system that adversely affects fuel flow or causes hazardous leakage during flight
Landing gear extensions or retractions, or opening or closing of landing gear doors during flight
Brake system component failures that result in loss of brake actuating force when the airplane is in motion on the ground
Aircraft structures requiring major repair
Cracks, permanent deformation, and corrosion of aircraft structures, if more than the maximum acceptable to the manufacturer or the FAA
Failure of aircraft components or systems that result in emergency actions during flight (except action to shut down an engine)

- Within the FAA it is the responsibility of MAC to issue the open-item status report and it is the responsibility of the FAA Principal Inspector to see that the open reports are closed out. However, the carrier has the over-riding responsibility to close out each occurrence.
- The data bank's main uses are:
  - To advise the FAA of problems and their current status
  - To advise carriers of occurrences
  - To advise prime aircraft manufacturers of occurrences

4.2 FAA Acquisition Concepts

4.2.1 Acquisition Concepts

Acquisition of systems within the FAA for use in the National Airspace System is guided by several key documents. The scope of these documents is outlined in the following paragraphs.

Electronic Equipment, General Requirements. FAA-G-2100, the electronic equipment general requirements specification (Key Document C-1), outlines the primary considerations a vendor must address when building equipments. The specification consists of five parts:

- Part 1: Electronic Equipment, Basic Requirements for All Equipments
- Part 2: Requirements for Equipments Employing Electron Tubes
- Part 3: Requirements for Equipments Employing Semiconductor Devices
- Part 4: Requirements for Equipments Employing Printed Wiring Techniques
- Part 5: Requirements for Equipments Employing Microelectronic Devices

These documents in turn cite and invoke selected sections of Department of Defense Specifications, including:

- MIL-STD-454 - Standard General Requirements for Electronic Equipment
- MIL-STD-785 - Reliability Program
- MIL-HDBK-217 - Reliability
- MIL-STD-470 - Maintainability Program

By further reference, DoD reliability and maintainability demonstration standards 781 and 471 are also invoked when necessary. Other FAA standards control other aspects of equipment procurement, (e.g., quality control, finances).

Reliability and Maintainability Policy, FAA 6000.26. This document, issued in August 1977, establishes reliability and maintainability policy for programs associated with acquisition and support of the National Airspace System. Major objectives are to (1) establish R&M program requirements for system acquisition and support process, (2) require and obtain deliveries of systems with specified R&M, and (3) assure that operational systems are performing in accordance with expectations and potential R&M improvements are identified.

R&M System Engineering Program (Key Document C-2). A comprehensive reliability and maintainability program plan, AAF 200, was implemented within the FAA in August 1976. The plan provides for the development of a series of planning and implementation documents and the performance of R&M

engineering tasks for new procurements and for fielded systems. The scope of these efforts are shown in the following outlines:

Planning Documents

(A) R&M System Engineering Program Plan

- Establishes overall R&M goals (e.g., zero maintenance growth)
- Defines levels and procurement types
- Defines tasks for new procurement
- Defines tasks for field improvements
- Defines AAF documentation requirements

(B) Optimum R&M Level Determination Guidebook for FAA Hardware Systems Provides Criteria and Procedures to Optimize MTBF and MTTR Specifications

(C) Guidebook for FAA Systems Availability

- Defines availability improvement techniques
    - Reliability
        - Components
        - Derating
        - Burn-in
    - Maintainability
        - Remoting
        - Condition monitoring and fault isolation
        - Modularity
        - Logistics
    - Reliability, Availability, and Maintainability (RAM) Program
        - Zero maintenance growth
        - Life-cycle cost

(D) Guidebook for Contractor Development Programs

- Defines program provisions and techniques
- Defines deliverables (documentation)
- Defines planning and control requirements
    - Component engineering
    - Design reviews
    - Data collection

- - Prediction (R&M)
  - Failure mode effects criticality analysis (FMECA)
  - Part control
  - Test and evaluation
  - Scheduling
  - Cost control

(E) Guidebook for Monitoring Contractor Programs

- Establishes adequacy of provisions and techniques
- Establishes timeliness of submittals
- Establishes monitoring of:
  - Preliminary and critical design reviews
  - On-site reviews
  - Planning and control provisions
  - R&M systems engineering provisions
  - Component engineering provisions
  - Test and evaluation provisions

(F) Maintainability Engineering Provides Guidelines for:

- Remoting
- Condition monitoring and fault isolation (CM and FI)
- Modularity
- Automation
  - Built-in-test, fault isolation test (BIT/FIT)
  - Diagnostics

(G) R Systems Engineering

- Provides prediction procedures
- Establishes failure mode analysis techniques
- Defines design review methods
- Provides failure recurrence control procedures
- Establishes maintenance analysis techniques
- Establishes procedures for use of R&M reference data
- Provides redundancy design approaches

(H) Component Engineering Procedural Manual

- Provides part technique selection
- Provides part specification procedure
- Establishes part control methods
- Defines nonstandard part approval procedures
- Establishes spare provisioning procedures

(I) R&M Testing Procedural Manual Provides Demonstration Procedures Covering:

- Full (statistical) demonstrations
- Limited (Bayesian) demonstrations
- Growth test procedures
- Acceptance test procedures
- Forced defect test procedures

(J) Data Collection and Reduction Procedures

- Establishes field data collection methods
- Establishes part failure mode and rate data production techniques
- Establishes production reject and degradation data collection methods
- Establishes factory and field cost data collection procedure
- Develops formats for field improvement recommendations
- Establishes requirements of R&M and LCC cost memory bank

(K) Failure Analysis Procedures

- Provides failure recurrence control procedures
  - R&M growth and demonstration
  - Production acceptance testing
  - Operation (field) trend reporting
- Provides failure analysis procedures
  - Equipment
  - Devices (microcircuits, high power tubes, etc.)

(L) Training Procedural Manual

- Provides training procedures
- Provides procedures for preparation and use of training aids

R&M Engineering Tasks (New Procurements)

(A) FAA Activities Prior to Contractor Performance

- System R&M Integration Studies
  - •• Establish R&M requirements for COO limits
  - •• Identify cost-effective procurement type
  - •• Perform trade-off analysis among reliability, maintainability, and cost
  - •• Identify critical components
- Procurement Package Review
  - •• Review specified R&M values
  - •• Review specified R&M program provisions
  - •• Review compliance requirements
  - •• Review documentation requirements
  - •• Review part control and subcontractor control provisions
- Liaison with Contractors
  - •• Assess and monitor contractor R&M efforts
  - •• Coordinate internal FAA R&M efforts

(B) FAA Activities During Contractor Performance

- R&M Assessment and Analysis
  - •• Perform independent R&M analyses (special studies)
  - •• Assess reliability of software
  - •• Perform human engineering analysis
  - •• Identify production R&M degradation factors
  - •• Conduct design reviews
  - •• Perform maintenance analyses
  - •• Identify R&M and cost-effective improvements
- Part Control Activity
  - •• Prepare and maintain project preferred parts list
  - •• Manage part approval control function
  - •• Define qualification and data requirements for parts
- R&M Compliance Activity
  - •• Review and evaluate R&M test plans and procedures
  - •• Retain R&M and cost memory bank data
  - •• Coordinate hardware failure analysis

R&M Systems Engineering Tasks (Fielded Systems)

- R&M Assessment of Fielded Systems
  - Determine R&M Field degradation factors
  - Compare actual R&M performance with expected values
  - Assess local operating procedures
- R&M Improvement
  - Select items for R&M improvement studies
  - Formulate cost-effective R&M improvement recommendations
  - Evaluate R&M improvements for cost-effectiveness
  - Monitor effectiveness of changes incorporated
- Failure Analysis
  - Select critical components for failure analysis
  - Coordinate hardware failure analyses
  - Prepare summary failure reports and failure alerts
- Data Collection
  - Collect R&M and cost data
  - Coordinate data collection with failure analysis and other efforts
  - Identify and list high-failure and high-downtime items
  - Reduce data, prepare failure mode, and rate reports
  - Prepare summary statistical reports

System Acquisition Publications

- System Acquisition Management - FAA 1810.1 - This document states a system management policy providing for an explicit evaluation of mission needs and program objectives to assure that the process for acquiring systems is efficiently and effectively accomplished. Contained within this document are a management framework and procedures to be used in the acquisition of major systems. Major objectives to be sought in system acquisition are stated:
  - Each system acquisition is directed toward fulfillment of a mission need.
  - The level of performance, maintainability, and reliability is in balance with the allocation of resources.
  - Appropriate trade-offs are considered among life-cycle costs, time schedules, and performance characteristics.
  - Strong management checks and balances are provided.
  - An acquisition strategy including logistics support for each system is planned and refined throughout the acquisition cycle.

- - A capability is maintained to: (1) estimate life-cycle costs; (2) predict, review, assess, and monitor costs for system development, engineering, design, demonstration, test, production, operation, and support; (3) assess cost schedules and performance experience against predictions, and provide such assessments for consideration by the Administrator or other top management officials at key decision points; and (4) make new determinations where significant cost, schedule, or performance variances occur.

- Major System Acquisition Review and Approval - DOT 4200 - This document was issued in 1977 and was developed in response to OMB Circular A109 and describes the approach to be used in acquiring major systems. Major life-cycle phases are outlined in Table C-3.

Table C-3. KEY DECISION POINTS IN SYSTEM LIFE CYCLES

Key Decision Points	Life-Cycle Phases
Starting point	Mission Needs, Identification, and Designation of Major Systems • Identify mission needs • Develop program to satisfy needs • Prepare initial acquisition paper and program/project plan
No. 1	Research Phase and Exploratory Development Phase • Potential system design concept studies • Preliminary research • Exploratory subsystem development • Update acquisition paper
No. 2	Advanced Development Phase and Prototype Development Phase • Design • Fabrication • Test • Evaluation • Update acquisition paper
No. 3	Preliminary Operational Deployment or Demonstration Phase • Full-scale (production) development • Independent tests of system performance • Demonstration in expected operational environment • Limited production • Update acquisition paper
No. 4	Operational Phase -- full production

4.2.2 FAA System Assessment

The FAA has developed the Maintenance Automated Reporting System (MARS), a computer program for the collection and dissemination of maintenance information regarding FAA facilities in the National Airspace System. MARS would use the computers already in place at the 20 NAS En Route Centers, which would in effect become system collection and dissemination points. The system keeps track of outages and provides individual system histories to which technicians can refer when correcting failures or working up schedules for preventive maintenance.

A further part of the AAF 200 R&M plan (part of Key Document C-2) is the development of an air R&M data bank and collection system. Data to be obtained for the system will include equipment and classification information as well as equipment experience data. When the data system is fully developed and implemented, it will provide output information such as reliability and maintainability parameters and cost data to support the R&M system engineering program (both documentation and engineering tasks).

4.3 Lead Responsibilities and Interface

The FAA assumes the lead role in assuring safety in the airways system; that, in turn, provides good system reliability as a direct benefit. To fulfill this role, the FAA has interfaces with the air carriers, equipment suppliers, and other government agencies such as the NTSB and the CAB. These relationships have developed over a period of years paralleling the growth of aviation.

5. COST AND EFFECTIVENESS

5.1 Program Cost

The specific amount spent by FAA on performance assurance is not known, but a review of some of the budget requests for FY 1978 could provide some insight.

FAA's total budget request for 1978 was $1,819,750,000. Of this, $203,389,000 was earmarked for administration of flight standards. This includes all of the certification efforts, safety programs, and inspection of flight facilities.

The 1978 equipment acquisition budget to supplement the National Airways System was $212,600,000. It is estimated that $6,990,000 of this amount will be spent on development and test and $469,646,000 on maintenance of the systems.

5.2 Program Effectiveness

FAA has been faced with severe technological growth problems as it has taken steps to automate the National Airways System to improve its productivity. As noted, its performance assurance for these systems is similar in many respects to the DoD concepts and its results are similar.

Systems acquired by the air carriers subject to FAA certification processes use a different approach, which has been shown to be cost-effective in producing reliable and safe systems. This approach places most emphasis on testing (certification) of the final product design and the product's being capable of performing its required function reliably. The air carriers through the development of system standards and their insistence on unity commitments aid further good reliability achievement.

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APPENDIX D

PERFORMANCE ASSURANCE PRACTICES OF THE NATIONAL TRANSPORTATION SAFETY BOARD

1. HISTORICAL DEVELOPMENT

The National Transportation Safety Board (NTSB) was created by the Department of Transportation Act of 1966, making the Board a part of the Department of Transportation. The Independent Safety Board Act of 1974 established the Safety Board as an entirely independent Federal agency, and broadened its responsibilities in the investigation and prevention of transportation accidents. The 1974 Act directed the Board to report to the Congress on July 1 of each year.

2. SCOPE OF CURRENT PRACTICES

2.1 NTSB Charter

Under its current charter NTSB is charged with:

- Investigating certain aviation, highway, railroad, pipeline, and marine accidents
- Reporting publicly on the facts, conditions, and circumstances, and the cause or probable cause of such accidents
- Issuing periodic reports to the Congress and to Federal, state, and local transportation safety agencies and others recommending measures to reduce the likelihood of transportation accidents
- Initiating and conducting special transportation safety studies and investigations
- Assessing accident investigation methods and publishing periodic recommendations on investigation procedures
- Establishing requirements for reporting accidents to the Board
- Evaluating and publishing findings on the transportation safety consciousness and accident prevention efficacy of other government agencies
- Evaluating the adequacy of hazardous materials transportation safeguards and procedures

* Reviewing on appeal the suspension, amendment, modification, revocation, or denial of certain operating certificates, documents, or licenses issued by the Federal Aviation Administrator and by the Commandant of the Coast Guard

2.2 Key Documents

The responsibility and authority of the National Transportation Safety Board are derived from:

* The Transportation Safety Act of 1974, Title III: "Independent Safety Board Act of 1974" (88 Stat. 2156,49 U.S.C. 1901)
* The Federal Aviation Act of 1958, August 23, 1958, as amended (72 Stat. 731,49 U.S.C. 1301)
* The Federal Railroad Safety Act of 1970, October 16, 1970 (84 Stat. 791,45 U.S.C. 421)

Regulations of the National Transportation Safety Board are published in the Federal Register and codified in the Code of Federal Regulations, Chapter VIII, Title 49 - Transportation.

2.3 Organizational Structure

NTSB is structured into the following four major bureaus.

2.3.1 Bureau of Accident Investigation

The Bureau of Accident Investigation is responsible for all accident investigations in the five modes of transportation: aviation, marine, railroad, highway, and pipeline. To aid the work of the Bureau, there are 12 field offices.

2.3.2 Bureau of Technology

The Bureau of Technology serves as the Safety Board's reservoir of technical expertise. Specialists from the Bureau provide support for both the Board's investigative and accident prevention activities. For example, specialists in the Division of Human, Vehicle, and Operational Factors as well as the Hazardous Materials Division contribute to accident investigations and take part in public hearings as members of technical panels. In aiding foreign accident investigations, this service includes using the Bureau's laboratory to examine vehicle parts or aircraft flight data and voice recorders recovered for foreign investigatory bodies.

2.3.3 Bureau of Plans and Programs

The Bureau of Plans and Programs was created to develop and manage the Safety Board's accident prevention and safety promotion programs. These programs include planning and conducting special studies. The Bureau also is responsible for determining the Safety Board's personnel training

requirements, planning safety program evaluations, and management reviews of safety activities. Finally, the Bureau is responsible for both proposing and advocating changes in Safety Board policy in the area of transporation.

3.2.4 Bureau of Administration

The Bureau of Administration was established to provide unified direction and management of the Safety Board's administrative programs. These programs include financial and personnel management, management analysis, and operations and facilities.

3. APPLICABILITY OF SELECTED PROGRAMS

The current charter of the MTSB permits it to have an impact on the electric power industry under its responsibilities for the transportation of hazardous materials. Its function as an independent investigator of accidents within the transportation industry is being met by NRC and local government agencies. However, it is considered of interest to view the approaches used by NTSB to gain insight toward reliability enhancement insofar as accident investigation techniques can be converted into power outage investigation techniques.

4. DESCRIPTION OF APPLICABLE PRACTICES

4.1 Key Program Elements

Major efforts of the NTSB are directed toward:

- Accident Investigation
- Safety improvement and recommendations program

Highlights of the activities in each area are outlined.

4.1.1 Accident Investigation

During 1976 the NTSB investigated 846 aircraft accidents and reviewed the 3448 accidents investigated by FAA. Additionally, the Board investigated 9 highway, 12 railroad, 5 pipeline, and 2 marine accidents.

The scope of an MTSB accident investigation is suggested by the following outline of a typical aircraft accident report.

- Synopsis
- Investigation
  - History of flight
  - Injuries to persons
  - Damage to aircraft

- • Other damage
- • Crew information
- • Aircraft information
- • Meteorological information
- • Aids to navigation
- • Communications
- • Aerodrome and ground facilities
- • Flight recorders
- • Wreckage
- • Medical and pathological information
- • Fire
- • Survival aspects
- • Tests and records
- • Other information

• Analysis and Conclusions

- • Analysis
- • Conclusions

• Recommendations

• Appendix A - Investigation and Hearing

• Appendix B - Crew Information

• Appendix C - Aircraft Information

• Appendix D - Approach Data

• Appendix E - Tower Transcript

• Appendix F - Flight Track

• Appendix G - Safety Recommendation

• Appendix H - Specialist Report

4.1.2 Safety Improvement and Recommendations Programs

During 1976 major NTSB activities for improving safety conditions are highlighted as follows:

• Aviation Safety

- • Reducing approach and landing accidents
- • Improved accident survivability

- Highway Safety
  - Improved traffic barrier crashworthiness
  - Reduced constructions zone hazard
  - Coordination of vehicle bumper standards
  - Safety belts for intercity buses
  - National driver register
- Marine Safety
  - Lighting of barges
  - Structural integrity of tank ships
  - Aids to marine investigations
- Pipeline Safety
  - Specialized regulations of highly volatile liquids
  - Maintaining of pipeline safety regulations
  - Protection of pipeline against construction damage
- Railroad Safety
  - Safety standards for rail rapid transit
  - Collision avoidance
  - Aids to accident investigation
  - Hazardous materials

The need for such projects is determined by the results of accident investigations conducted. As a result of these studies, NTSB makes, as appropriate, specific recommendations to Congress for new laws governing safety.

4.2 Lead Responsiblities and Interfaces

NTSB has the lead responsibility for accident investigation as chartered by the enabling legislation. However, in the discharge of this responsibility it interfaces with several other government agencies including:

- FAA
- The Bureau of Motor Carrier Safety
- National Highway Traffic Safety Administration
- The Office of Pipeline Safety Operations
- U.S. Coast Guard
- Federal Railroad Administration

These agencies may support NTSB in the conduct of an investigation or may conduct the total investigation with the results being reviewed by NTSB.

Industry participates as part of the NTSB investigation activity and in studies leading to possible changes in safety rules as they apply to the transportation field.

5. COST AND EFFECTIVENESS

5.1 Cost

The cost of running the NTSB in FY 1977 was $13,800,000 and for FY 1978 is forecast to be $14,710,000. Of this, approximately one-half is spent on accident investigation.

5.2 Program Effectiveness

The results of the accident investigation and the other studies conducted by NTSB has led to the identification of technological, procedural, environmental, or operational causes. This identification has led in many cases to ameliorative actions which precluded further occurrences. Considering the magnitude of the potential casualty loss of a large aircraft, the cost of accomplishing the investigation and analysis seems justified.

APPENDIX E

PERFORMANCE ASSURANCE PRACTICES OF THE URBAN MASS TRANSIT ADMINISTRATION (UMTA)

1. HISTORICAL DEVELOPMENT

Since 1964, UMTA has provided capital assistance, technical assistance, and operating subsidies to communities for improving existing mass transportation systems and developing new transit systems. UMTA is supporting transit construction in Atlanta, Baltimore, Philadelphia, Buffalo, Detroit, Miami, Houston, Cleveland, Los Angeles, and St. Paul.

The principal role of UMTA has been to act as a funnel through which Federal money flows back to the cities, states, and certain private companies. Increasingly, UMTA is interested in improving the effectiveness of both Federal investment and investment by local communities. Therefore, over the last two to three years, UMTA has broadened its previous interest in safety as the primary measure of system performance to include life-cycle cost and system reliability, maintainability, and availability as important measures of system performance.

The increasing emphasis on improving performance assurance was prompted by the very low, initial, service availability* of advanced transit systems (e.g., the San Francisco Bay Area Rapid Transit System - BART) and specialized demonstration systems (e.g., the Morgantown People Mover) that had received UMTA funds. UMTA was also criticized by the Government Accounting Office (GAO) in 1976 for its inability to assure the reliability of rail cars purchased by the New York Transit Authority and communications equipment purchased by the Chicago Transit Authority. UMTA has responded to these criticisms by developing a performance assurance program as described in the remainder of this section.

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*UMTA employs the concept of "service availability" in such a way that the system is declared unavailable if any passenger cannot complete his trip in a prescribed nominal time.

2. SCOPE OF CURRENT PERFORMANCE ASSURANCE ACTIVITIES AT UMTA*

Although UMTA is beginning to recognize the need for a more cohesive and centralized approach to performance assurance, there is currently only one focal point for performance assurance activities within the agency -- the Mass Transit Safety and System Assurance Program (MTSSA).

As the title of the program suggests, the emphasis within the Mass Transit Safety and System Assurance Program has been on safety. However, in FY 1976 the activity was reassigned to the Office of Technology Development and Deployment. At the same time, the emphasis was shifted to allow the optimization of safety and security in consideration of other system values, thereby suggesting a growing role for UMTA in helping to improve system availability, system dependability, equipment maintainability and reliability, and life-cycle cost.

The management of the MTSSA program is oriented to assist in and contribute to the quality of local and regional decision-making processes applied to the development of new transit systems, and the improvement or expansion of existing systems, based on three considerations:

1. Recommend rather than require.
2. Recognize that ultimate accountability for system operational viability lies with local or regional decision makers accountable to the public for system acquisition and operation.
3. Avoid preemption of local accountability for decision.

In applying the MTSSA program, UMTA employs a functional approach, an organizational approach, and a management approach.

The functional approach follows these guidelines: safety of the system is not paramount; safety and other contributors to the operational viability of a system are interdependent (competitive and contributing); the highest practicable level of safety is not achievable without concurrent consideration of other contributors (informed decisions); operational viability is a system life-cycle consideration; the focus is on operational needs; and it is better to preempt than to react.

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*UMTA policy with respect to performance assurance and the scope of UMTA performance activities are in a state of transition. The summary offered here is our own interpretation of the changing scene and may not reflect all viewpoints or adequately represent the result of recent management deliberations.

The organizational approach includes the involvement of the Transportation Systems Center (TSC), the industry associations, and the Transportation Safety Institute. Explicit guidelines are: UMTA's role is to be limited; there is a need for department level participation; there is a need to maintain strong communications and interactions with experienced transit managers; and there is a need for industry and government education and instruction.

The management approach is defined as a sequential closed-loop iterative process undertaken to: endorse and commit to transit; stimulate and assist transit; learn and assimilate from transit; and evaluate, recommend, and negotiate with transit.

3. APPLICABILITY OF UMTA METHODS TO THE ELECTRIC POWER INDUSTRY

Local mass transit authorities rarely have the engineering expertise necessary to design and manage the construction of a mass transit system. Typically, they delegate the management and coordination responsibilities to a prime contractor, who designs the system in cooperation with consultants and manages subcontractors to build it. That practice is similar to the electric power industry retention of an architect-engineer for design and to oversee procurement and construction. UMTA, recognizing that most local mass transit authorities and many prime contractors have no formal performance assurance program, has provided guidelines for installing formal programs and gives courses to acquaint local mass transit authorities with the concept and implementation methods. The U.S. Department of Energy could also prepare program guidelines and give courses to acquaint electric power utilities with performance assurance concepts and techniques. The U.S. Department of Energy could also sponsor EPRI, EEI, IEEE, or another industry association to follow UMTA's example.

4. DESCRIPTION OF APPLICABLE PRACTICES

4.1 Key Program Elements

The MTSSA program is currently thrusting in two directions. One thrust is to sponsor a number of education and instruction courses to introduce the transit industry to performance assurance concepts. The other thrust is to stimulate metropolitan transit authorities in implementing local performance assurance programs. The Metropolitan Atlanta Rapid Transit Authority (MARTA) is the first authority to make a commitment to undertake formalized research, review, and a systematic approach to the integration and implementation of the MTSSA at the local level.

4.1.1 Education and Instruction

The following instruction courses have been developed and implemented or are scheduled for future development and implementation (in cooperation with DOT's Transportation Safety Institute in Oklahoma City).*

A. Introduction to Mass Transit Safety and System Assurance - A five-day course implemented in September 1976, scheduled to be given quarterly.

B. Quality Assurance - A five-day course, implemented in November 1976, scheduled to be given quarterly.

C. System Safety - A five-day course, implemented in January 1977, scheduled to be given quarterly.

D. System Security - A five-day course currently under development, to be implemented in FY 1978.

E. Reliability, Maintainability, Availability, Dependability (RMAD) - A five-day course currently under development to be implemented in November 1977.

F. Human Factors - A five-day course to be developed and implemented in FY 1978.

4.1.2 MARTA Safety and System Assurance (Performance Assurance) Project Objectives

The objectives of the MARTA performance assurance project are summarized in Figures E-1 and E-2.**

4.1.3 MARTA Reliability Program Plan

The MARTA Reliability Program Plan, prepared by Parsons and Brinkerhoff, Tudor Engineering, and Bechtel (PBTB), the general engineering consultants, is an excellent example of a complete performance assurance program (Key Document E-1). An outline of the planned reliability program taken from Key Document E-1 follows:

A. Management

- Delegation of authority - PBTB to assist in the development and the implementation of the reliability program and perform all reliability analysis and related technical studies.
- Organizational responsibility - Responsibility and line of authority defined explicitly by title and name.

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*This information was taken from a widely distributed letter from George J. Pastor, Associate Administrator for Technology Development and Deployment, UMTA, July 1977 (project DC-06-0139).

**W. E. Gooden and A. M. Lock, "Safety and System Assurance Resources Applied to the Design and Development of a Rail Rapid Transit System", Third International System Safety Conference, Washington, D.C., 17-21 October 1977.

System Safety Program Plan	Reliability Program Plan	Maintainability Program Plan
Establish system safety goals and criteria and implement them throughout the system. Identify and assess system safety hazards as early as possible in the design phase. Take appropriate actions to eliminate, minimize, or control the identified critical or catastrophic hazards. Verify the MARTA system as safe for revenue service prior to opening date.	Establish state-of-the-art reliability requirements, specifications, and criteria. Ensure contractor and vendor compliance with all reliability requirements, specifications, and criteria. Verify the reliability potential of the MARTA rail network through system and subsystem analyses and equipment demonstration testing initiated prior to revenue service. Isolate and correct potential reliability problems. Reverify the reliability potential of the MARTA rail system through total-system-integration testing initiated prior to revenue service. Continuously assess the inherent reliability of the MARTA rail system as a function of failure data collected during testing. Demonstrate achievement of all reliability requirements, specifications, and criteria.	Establish the maintenance concept and goals for the MARTA system. Establish the methods by which the maintenance goals will be met. Incorporate maintainability concepts into the design to optimize maintenance with respect to personnel, safety, personnel skill levels, reliability, and logistics support. Monitor maintainability design analyses and predictions. Support operational procedures relative to maintainability concepts in areas of design assembly, testing, installation, and operation. Support the test and evaluation program for maintainability assistance in repairs, installation, and analyses.

Figure E-1. MARTA SAFETY AND SYSTEM ASSURANCE PROGRAM OBJECTIVES

Quality Assurance Program Plan	Fire Protection Discipline	Security Discipline
Assure that all work performed for the transit system is performed in accordance with the engineering requirements. Assure that all equipment is tested throughout development, manufacture, and installation to verify functions as specified. Assure that undesirable conditions are detected, and positive corrective action performed promptly. Assure that control over the configuration is maintained at all times to enable timely correction and improvements.	Provide MARTA fire protection and life safety equivalency levels for: • The prevention of fire • The protection of the general public, MARTA employees, and fire department personnel from injury due to fire, smoke, explosion, or panic • The protection of MARTA structures and equipments from damage due to fire as otherwise provided through local codes and as appropriate for the unique aspects of a rail rapid transit system	Provide that security is conceptually designed and built into the system in a manner that assures a real as well as a high perceptual level on the part of patrons and personnel for the assurance of: • Patron and personnel safety • System integrity • Patron assistance

Figure E-2. MARTA SAFETY AND SYSTEM ASSURANCE PROGRAM OBJECTIVES

- Reliability integration - MARTA to coordinate reliability efforts with related disciplines such as maintainability, safety, quality assurance, design and operations.
- Reliability standardization - Emphasis placed on proven rapid transit design techniques, equipment, and hardware.

- Equipment contractor controls - MARTA to generate reliability specifications, requirements related to equipment and hardware; all major contractors, subcontractors, and suppliers to submit formal reliability program plans.
  - •• Reliability design analysis
  - •• Reliability parts program and controls
  - •• Reliability failure modes and effects analysis (FMEA)
  - •• Reliability prediction analysis
  - •• Reliability data collection techniques and sources
  - •• Reliability failure criteria for demonstration and acceptance testing
  - •• Reliability problems
  - •• Reliability progress reports
- Reliability program reviews - MARTA to conduct periodic program reviews at established reliability milestones. The content of reviews includes:
  - •• Reliability program objectives
  - •• Current reliability requirements, estimates
  - •• Potential reliablity problems
  - •• Controls and procedures
  - •• Reliability parts applications and controls
  - •• FMEA
  - •• Reliability trade-offs and related effects on other disciplines
  - •• Status of reliability programs
  - •• Overall reliability impact
  - •• Reliability status reporting - monthly
  - •• Reliability consultant - retained by MARTA
    - ••• Reliability analysis
    - ••• Reliability allocations
    - ••• Reliability predictions
    - ••• Reliability trade-off studies
    - ••• FMEA
    - ••• Functional models
    - ••• Mathematical models
    - ••• Reliability training - MARTA to disseminate requirements, specifications, and criteria by directives, memoranda, procedures, conference meetings, written and oral communications, formal seminars

B. Reliability Design and Analysis

- Design techniques - MARTA to sign off on design drawings and technical data regarding:
  - •• Stress and derating factors
  - •• Redundancy
  - •• Stress-strength margins
  - •• Nondegraded performance capability at all required environmental levels
  - •• Criticality, upgrading
  - •• System and subsystem integration
  - •• Compatibility with diagnostic test equipment
- Stress analysis - MARTA reviews design drawings for functional and environmental stress levels, considering real-time operating conditions.
  - •• Functional factors
    - ••• Hardware locations
    - ••• Positioning
    - ••• Alignments
    - ••• Interfacing
  - •• Environmental factors
    - ••• Vibration
    - ••• Temperature
    - ••• Humidity
    - ••• Wind gusting
  - •• Design reviews - reliability specialists will support engineering in reviewing:
    - ••• Current reliability requirements and estimates
    - ••• Problem areas
    - ••• Controls and procedures
    - ••• Parts
    - ••• FMEA
    - ••• Trade-offs
    - ••• Reliability program status
    - ••• Status of previously approved design review action items

- Reliability analysis - system status analysis to evaluate impact of performance, design, and operational objectives or the formulation of reliability allocations and predictions. Consider:
  - System definitions
  - Functional flow diagrams and math models
  - Math model predictions in comparison with allocated requirements
  - Impact of changes on reliability predictions
- Reliability allocations - reliability math model to be formulated early in the program to allocate overall system reliability requirements down to the subsystem and equipment levels. Allocation changes to be justified by either contract or specification revision.
- Reliability predictions - MARTA to perform predictions analysis of system using aforementioned math model.
  - Identify potential problem areas
  - Provide a guide for additional inputs to the FMEA
  - Begin at the piece-part level
  - Identify critical parts
  - Study system effectiveness
  - Provide historical data (by MARTA)
- Reliability parts selection - preferred parts list supplied by MARTA, screening techniques, predict reliability in consideration of stress and environment.
- FMEA - MARTA to analyze rail system to determine possible modes of failure and effects on revenue service.
  - Identify critical failure areas
  - Conduct FMEA down to lowest replaceable module level
  - Consider
    - Module function
    - Means of detection
    - Corrective action
    - Likelihood of failure
    - Wear-out
    - Performance degradation
    - Environmental stresses
    - Safety hazards
    - Random catastrophic failures
    - Human error

    - Documentation - nomenclature specified in detail
    - To be used as the baseline of a maintainability engineering analysis (MEA)
    - Input to reliability demonstration test plans, defining test conditions

- Reliability demonstration and acceptance testing - MARTA to develop and coordinate development of test plans for critical systems.
  - Verify reliability design analysis
  - Verify FMEA
  - Verify reliability predictions
  - Test parameters specified by MARTA
    - Number of test units
    - Total hourly test time
    - Accept-reject criteria
    - Statistical confidence levels
- Reliability assessment - MARTA to develop statistical assessment technique for estimating the inherent reliability of critical systems based on all research, development, and acceptance test data. Aimed at guiding corrective effort where reliability achievement falls short of established requirements.
- Failure data reporting, analysis, and corrective action - MARTA to administer a strictly controlled system for the reporting, analysis, correction, and data feedback on all equipment failures detected during fabrication, testing, and operation.
- Reliability Documentation - to be submitted by MARTA
  - Reliability program plan
  - Reliability trade-off studies
  - Reliability analysis
  - Reliability design criteria
  - Reliability allocations and requirements
  - Reliability test plans and reports
  - Reliability progress and status reports
- Reliability Records and Files
  - Traceability
  - Centralized information availability

4.2 Lead Responsibilities and Government-Industry Interface

The lead responsibility for assuring that the performance assurance program is implemented lies with the local mass transit authority. The authority is motivated by UMTA's requirement of the program and reviews it as a condition for allocating federal funds to the project. UMTA guides the local authorities through these reviews and guides the entire transit community by means of the UMTA-sponsored educational courses.

5. COST AND EFFECTIVENESS

Although detailed performance assurance cost information is not available, it appears that expenditures for performance assurance by MARTA are from 0.01 to 0.2 percent of system acquisition costs.

The effectiveness of the program cannot be determined because no mass transit system has been built and operated in accordance with the UMTA guidelines. However, systems built without applying a comprehensive performance assurance program have experienced severe reliability and maintainability problems and, hence, severe service availability problems.

APPENDIX F

PERFORMANCE ASSURANCE AS PRACTICED BY
THE NUCLEAR REGULATORY COMMISSION (NRC)

1. HISTORY AND SCOPE OF PERFORMANCE ASSURANCE ACTIVITIES

Under the Energy Reorganization Act of 1974, NRC became responsible for implementing all regulatory requirements of the Atomic Energy Act of 1954, as amended. The system of licensing and regulation devised to carry out NRC's mission is implemented through rules and regulations under Title 10 of the Code of Federal Regulations (CFR). An important part of this mission is the consideration of applications to construct and operate nuclear power plants.

The NRC licensing process is a two-stage procedure. The initial stage consists of the filing by the utility and review by the NRC staff of an application for a construction permit. The second stage consists of the filing by the utility and review by the staff of an application for an operating license. A substantive part of the two applications pertains to quality assurance program requirements described in Title 10 of the CFR, Part 50, Appendix B (Key Document F-1). These requirements were published in July 1970 and define the elements of a quality assurance program derived from military programs. Detailed descriptions of program elements and requirements are given in NRC's standard review plans, "Quality Assurance During the Design and Construction" (Key Document F-2) and "Quality Assurance During the Operations Phase" (Key Document F-3).

NRC also evaluates the performance of nuclear power plants. Two important evaluation (data feedback) tools are the licensee event reports (LERs) and the NRC Gray Book.*

The LER file contains descriptions of those plant events in violation of technical specifications primarily in safety-related equipments, furnished to NRC by licensees. NRC furnishes a bi-weekly summary of LERs. Outage data are not normally provided; the Nuclear Safety Information Center (Oak Ridge)

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*A comparison of nuclear industry data bases with a nominal performance ideal is given by M.E. Lapides and Edwin Zebroski in the EPRI report "Use of Nuclear Plant Operating Experience to Guide Productivity Improvement Programs", EPRI, Palo Alto, California. The summary offered here is based on the EPRI report.

periodically republishes the LER file and adds topical summaries, distributional studies, and other data, typically as available from foreign sources and research reactor experience.

The NRC Gray Book is a monthly summary of plant performance data, by plant, for each reactor licensed for commercial service. Forced and scheduled outage data are provided by plant system, subsystem, and component descriptors.

A related effort is the Nuclear Plant Reliability Data System (NPRDS), initiated by EEI/ANSI and being implemented by Southwest Research Institute based on data voluntarily provided by utilities. The system, when completed, will contain a "pedigree list" (detailed design data) for plant safety-related equipment and lists of "failure" incidents reported against that pedigree list by utilities.

Another aspect of NRC's performance assurance activities is the development of standards. The Office of Standards Development publishes Regulatory Guides which are "issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants ... compliance is not required .... Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission". These guides often cite and approve industry standards.

The guides are issued in the following ten broad divisions:

- Power reactors
- Research and test reactors
- Fuels and materials facilities
- Environmental and siting
- Materials and plant protection
- Products
- Transportation
- Occupational health
- Antitrust review
- General

2. APPLICABILITY OF NRC PERFORMANCE ASSURANCE ACTIVITIES TO BALANCE-OF-PLANT AND NON-NUCLEAR POWER PLANTS

As pointed out by Lapides and Zebroski, the most clear-cut incentive to improve the performance of nuclear plants derives from the cost of replacement power. The effect of a single day's outage of a 1000 MWe nuclear unit has a current value of $250,000 to $1 million depending on local fuel situations. The dollar magnitude, the impact on the cost of service, and the necessity of payments from short-term cash assets are the major sources of utility incentives.

However, if the cost of outages is to be reduced by applying performance assurance techniques to balance-of-plant and non-nuclear power plants, it will be necessary to face the institutional problems related to the utilities being separate and individual corporations served during their design, construction, and operation by a variety of independent firms, contractors, and suppliers. It is within the context of the "institutionalization" problem that NRC's safety-oriented performance assurance programs offer the greatest potential. The electric power industry (at least those segments that have installed nuclear units) has succeeded in applying and using the methods and techniques required to meet NRC regulations. Although these methods and techniques (and the paperwork) were expensive to incorporate, most utilities and supporting firms have succeeded in not only incorporating them but in applying them efficiently and effectively. NRC has helped to simplify them and reduce the cost of their incorporation; for example, NRC now approves generic, topical reports so that the rather limited number of firms that provide nuclear steam system supplies, architect/engineers, construction, and construction management services need only refer to the generic, topical report in most applications (29 such reports have been accepted by NRC). Also, NRC has approved standard plant designs that may reduce not only the cost of meeting regulatory requirements, but may help reduce rapidly escalating design and construction costs. In short, the power industry has already installed safety-oriented performance assurance programs, thereby paving the way for a broader emphasis. It is conceivable that the incremental cost of applying performance assurance methods and techniques to improve investment effectiveness, reduce life-cycle costs, and improve service may be comparatively small if applied in conjunction with NRC requirements by those who are experienced in dealing with NRC requirements. Victor Stello, Jr., has made some recommendations in this regard.* Many parts of NRC's Quality Assurance Program are applicable to balance-of-plant and non-nuclear plants.

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*V. Stello, Jr., "Some Bases for a Systematic Program to Enhance Nuclear Plant Reliability," Executive Conference on Improving Powerplant Reliability, The Homestead, Hot Springs, Virginia, 27-29 September 1976.

3. DESCRIPTION OF APPLICABLE PRACTICES

3.1 Key Program Elements

NRC requires all applicants to institute a 18-element quality assurance (QA) program. These are summarized below.*

3.1.1 Organization

- The applicant must remain responsible for the establishment and execution of the QA program.
- The applicant may delegate the work of establishment and execution.
- The authority and duties of persons and organizations performing QA functions must be clearly established and delineated in writing.
- Persons and organizations performing QA functions must be permitted sufficient authority and organizational freedom to remain independent of cost and schedule when those considerations are opposed to safety considerations.

3.1.2 General QA Program Requirements

- The QA program must be documented by written policies, procedures, or instructions.
- The QA program must be carried out throughout plant life.
- The applicant must identify the structures, systems, and components to be covered by the QA program.
- The applicant must identify the major organizations participating in the program and their assigned QA functions.
- Activities affecting quality must be accommodated under suitably controlled conditions taking into account the need for special controls, processes, test equipment, tools, skills, verification by inspection, and test.
- The program must provide for indoctrination and training of personnel performing activities affecting quality.
- The applicant must regularly review the status and adequacy of the QA program.

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*We have chosen to follow NRC's use of the word "must" in describing assurance requirements. By doing so, we do not mean to imply that envisaged extensions of these requirements to balance-of-plant and non-nuclear plants should be legislated. The word "must" can be interpreted in a contractual sense.

3.1.3 Design Control

- Measures must be established:
  - To assure that regulatory requirements are correctly translated into specifications, drawings, procedures, and instructions
  - To assure that appropriate standards are specified and included in design documents
  - For selecting and reviewing the suitability of materials, parts, equipment, and processes
  - For identifying and controlling design interfaces and for coordinating among design organizations
- Design control measures must provide for verifying the adequacy of design as by:
  - Performing design reviews
  - Using alternate calculational methods
  - Performing a suitable test program
- Verification must be performed by individuals or groups other than the original designers.
- Tests to verify design adequacy, used in lieu of other verification processes, must include qualifications testing of a prototype under the most adverse design conditions.
- Design changes must be subjected to design control measures commensurate with those applied to the original design and be approved by the original design organization or other independent designee.

3.1.4 Procurement Document Control

- Applicable regulatory requirements, design bases, and other QA requirements must be cited in procurement documents.
- Procurement documents must require contractors and subcontractors to provide an appropriate quality assurance program.

3.1.5 Instructions, Procedures, and Drawings

- Activities affecting quality must be prescribed and accomplished in accordance with documented instructions, procedures, or drawings.
- Instructions, procedures, and drawings must include appropriate acceptance criteria.

3.1.6 Document Control

Measures must be established to control the issuance of documents which prescribe QA activities and assure that they are reviewed for adequacy.

3.1.7 Control of Purchased Material, Equipment, and Services

- Measures msut be established to assure that purchases conform to procurement documents and quality requirements.
- Documentary evidence that material and equipment conform to procurement requirements must be available at the nuclear power plant site.

3.1.8 Identification and Control of Materials, Parts, and Components

Identification and control measures must be designed to prevent the use of incorrect or defective material, parts, or components.

3.1.9 Control of Special Processes

Measures must be established to assure that special processes including welding, heat treating, and nondestructive testing are controlled and accomplished:

- By qualified personnel
- Using qualified procedures
- In accordance with applicable codes, standards, specifications, criteria, and other special requirements

3.1.10 Inspection

- A program for inspection of process monitoring of activities affecting quality must be established.
- Inspections must be performed by individuals other than those who performed the activity.
- Both inspection and process monitoring must be provided when control is inadequate without both.
- Mandatory inspections without which work cannot proceed must be identified in appropriate documents.

3.1.11 Test Control

- A program must be established to assure that all testing required to demonstrate satisfactory in-service performance is identified and performed in accordance with written test procedures.
- The test program must include:
  - Proof tests prior to installation
  - Preoperational tests
  - Operational tests
- Test results must be documented and evaluated to assure that test requirements have been satisfied.

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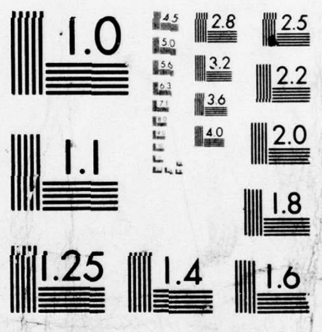

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

3.1.12 Control of Measuring and Test Equipment

Measures must be established to assure that tools, gages, instruments, and other measuring and testing devices are properly controlled, calibrated, and adjusted at specified periods.

3.1.13 Handling, Storage, and Shipping

- Measures must be established to control handling, storage, shipping, cleaning, and preservation of material and equipment in accordance with work and inspection instructions.
- Special protective environments must be specified and provided if necessary.

3.1.14 Inspection, Test, and Operating Status

- Measures must be established to mark the status of inspections and tests performed upon individual items.
- Measures must be established for indicating the operating status of structures, systems, and components to prevent inadvertent operation.

3.1.15 Nonconforming Materials, Parts, or Components

- Measures must be established to control materials, parts, or components which do not conform to requirements to prevent inadvertent use.
- Nonconforming items must be reviewed and accepted, rejected, repaired, or reworked in accordance with documented procedures.

3.1.16 Corrective Action

- Measures must be established to assure that failures, malfunctions, deficiencies, deviations, defectives, and nonconformances are promptly identified and corrected.
- In the case of significant conditions adverse to quality, the cause of the condition must be determined.
- The cause of the condition and the corrective action taken must be documented and reported.

3.1.17 Quality Assurance Records

- Operating logs and the results of reviews, inspections, tests, audits, monitoring of work performance, and materials analysis must be recorded and maintained.
- Records must also include qualifications of personnel, procedures, and equipment.

- Inspection and test records must identify the inspector or data recorder, the type of observation, the results, the acceptability, and the action taken in connection with deficiencies noted.
- The applicant must establish requirements concerning record retention, such as duration, location, and assigned responsibility.

3.1.18 Audits

- A comprehensive system of planned and periodic audits must be carried out to verify compliance and determine the effectiveness of the quality assurance program.
- Audits must be performed in accordance with written procedures or check lists.
- Audit personnel must be appropriately trained.
- Audio personnel must not have direct responsibility in the areas being audited.
- Audit results must be documented and reviewed by those responsible in the audited area.
- Follow-up action including reaudit of deficient areas is required.

3.2 Lead Responsibilities and Government-Industry Interface

Although NRC provides the impetus for applying the quality assurance program and has the ultimate responsibility for approving the quality assurance plan and the result, the licensee is responsible for applying the program. Typically, the licensee delegates a considerable portion of the implementation responsibility to specialized contractors, thereby creating a vertically integrated situation held together by legislated regulations at the top and contractual requirements at the bottom.

4. COST AND EFFECTIVENESS

NRC's annual operating budget is about $281 million.

It is difficult to objectively judge the effectiveness of NRC's program because numerical performance goals such as mean time between failures (MTBF) and mean time to report (MTTR) are not specified and allocated. It is interesting to note that NRC has sponsored one of the most comprehensive and well-documented studies of quantitative risk ever assembled, but has not converted the results into goals.

APPENDIX G

AMERICAN TELEPHONE AND TELEGRAPH (AT&T)

1. HISTORICAL DEVELOPMENT

Performance assurance policies, procedures, and practices are interwoven into the fabric of the Bell System* organization structure in such an intimate way that it is difficult to separate the performance assurance functions from any other. The organizational structure and capital plant have grown together over many years. In fact, Bell's performance assurance program is the most highly evolved of any discussed in this report. Because it has been relieved from the pressure of external competition, Bell System management has been able to introduce new technology at an incremental rate and to continually develop, refine, test, and formalize an organizational structure to cope with and utilize new technology very effectively.

2. SCOPE OF PERFORMANCE ASSURANCE PRACTICES

Every step in the research, development, manufacture, installation, testing, and operation process is coordinated and integrated by AT&T policy guidelines, organizational charters, and standard practices which are used throughout the Bell System. The results is a sophisticated, vertically integrated, closed-loop performance assurance program of unrivaled scope and depth.

AT&T** is the headquarters organization, which coordinates the entire enterprise in five ways:

- By stock ownership in the operating companies
- By functioning as a general staff to assist the 23 operating companies
- By furnishing, through its Long Lines Department, interstate service between the different operating companies

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*The word "system" as used here follows AT&T's use of the word to denote the combination of organization and plant required to deliver telecommunication service.

**AT&T consists of the general department (designated "195") and the Long Lines Department.

* By ownership of the Western Electric Company, the manufacturing and supply unit of the Bell System
* By ownership, with Western Electric (50-50), of the Bell Telephone Laboratories (BTL), which performs research, development, and testing work to improve capital plant

BTL had 16,000 employees in 1975. It is funded by the operating companies and the Long Lines Department for research and fundamental development ($227 million to $250 million in 1975), by Western Electric for specific development, design, and testing ($321 million in 1975), by the operating companies for information systems ($35 million to $65 million in 1975), and by the U.S. Department of Defense ($53 million in 1975). Usually, BTL has spent roughly equal amounts on electronics, transmission, and switching, equally divided between research and customer products.

Western Electric, with 153,000 employees, spends about 60 percent of its annual budget on manufacturing, about 33 percent on services (mainly installation), and about 7 percent on purchasing and transportation. Sales in 1975 were $6,127 billion of which 93 million were to the Bell System*.

Both BTL and Western Electric play key roles in establishing performance assurance goals, defining performance assurance requirements, and implementing performance assurance programs.

3. APPLICABILITY OF BELL SYSTEM PRACTICES TO THE ELECTRIC POWER INDUSTRY

The aspects of the Bell System's approach to performance assurance which are most unusual are the organizational aspects. Bell has organized performance assurance on a national scale. The implementation structure is vertically integrated in a manner and to an extent that may not be applicable in the electric power industry, but the Bell System organizational precedent is worth examining if only to show how a national-scale performance assurance program could make use of centralized and shared skill banks (like BTL's); coordinated manufacturing, installation, and repair services (like Western Electric's); and vertically integrated maintenance on a national scale (like that of the operating companies, Western Electric, and BTL).

Also, the Bell System displays a unique ability to manage technological change. Bell does so by requiring extensive field trials of prototype equipment, before making new equipment available for general purchase, deploying specialized technical teams to respond to new equipment problems, collecting and analyzing performance data in three tiers, standardizing equipment at the major component level in the system, and continually analyzing optimum levels of redundancy at local and national levels. These methods of managing technical change should be considered by the Department of Energy (DOE) and the power industry to the extent that anti-trust legislation allows.

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*Recently, Western has begun selling complete telephone systems to underdeveloped countries.

4. DESCRIPTION OF APPLICABLE ORGANIZATION AND PRACTICES

4.1 Bell Telephone Laboratories' Role

As a general function performance assurance task, BTL controls the rate at which new technology is introduced into the system. BTL performs this function during the research and fundamental development phases by assessing, for cost-effective application to the Bell System, new technological developments derived from outside and inside the Bell System. The tendency is to open the new technology "filter" as wide as possible during the research phase and reduce the filter aperture during the fundamental development phase by applying BTL's intimate and sophisticated knowledge of deployment and operating constraints -- both economic and technical. During the specific development phase, BTL concentrates on proving that the technology can be applied as predicted. BTL practices the "informed decision" approach to the process of applying new technology with primary emphasis on the "informed" part of the phrase. BTL proceeds slowly, allowing plenty of time to cope with infant mortality problems, recognizing that economies of scale can only be realized when the technology reaches maturity.

Typically, the associated companies request that BTL design a new item. BTL is funded for an initial study during which corporate-wide requirements with respect to cost and compatibility are investigated thoroughly. Availability, reliability, and maintainability requirements are derived from cost and compatibility considerations. BTL then designs and builds prototypes for field trial and, in the process, designs appropriate test equipment and procedures, diagnostic techniques, redundancy rules, and technical specifications. BTL also provides a detailed maintenance plan that is refined as the system is developed and field-tested.

4.2 Western Electric's Role

Western Electric plays a major role, with BTL, in addressing installation and logistical support requirements during the specific development phase. Western Electric manufactures the items to BTL's specifications, develops engineering and operating standards, and publishes appropriate Bell System Practices (e.g., test standards that define how the item should be tested on a stand-alone and installed basis). One of Western Electric's major roles is quality assurance. Typically, Western Electric places more emphasis on screening and qualification testing than would be the case if there were competitive pressures to get into production.

4.3 The Role of the Operating Companies

Because the operating companies have direct interfaces with customers, there is strong emphasis on immediate response to service calls. Each company maintains highly trained and, typically, very experienced diagnostic and repair crews. These crews are members of a vertically integrated group of engineering personnel who play central roles at each level in the entire Bell System organization. They pass along problems and solutions as

necessary. In essence, the maintenance and repair functions are performed within a specialized vertical organization that is nominally separable from and parallel to the main structure. Thus, all operating companies and each customer is able to utilize the services of top echelon personnel at BTL, Western Electric, and Long Lines, if necessary. Specialization increases from the top down, whereas experience and education increase from the bottom up.

4.4 Field Trials

The Bell System employs acceptance and demonstration testing less frequently than is typical when new items are acquired and operated by separate organizations. Instead, Bell relies on extensive field trials performed by a team comprising BTL, Western, 195, and one or more operating companies (and/or Long Lines). Many of the trials last months and some last years. They are used to work out bugs, demonstrate reliability and maintainability, assess economic and organizational impact, and prepare operating plans, procedures, and standard practices.

4.5 The Technical Centers Concept

When a new technology is introduced, Bell augments the maintenance and repair structure described above by training and deploying special teams organized in "centers". These centers respond to maintenance and repair requests from any operating company. The first of such centers was a group of Data Technical Assistance Centers (DATAC) organized to deal with data communications problems. DATAC was so effective that Bell is training and will soon deploy other center teams such as SCOTS (Surveillance and Control of Transmission Systems), ESSTAC (Electronic Switching System Technical Assistance Centers), the Centralized Data Testing Centers, and the Facility Maintenance Management Centers.

4.6 Performance Data Systems

After an item has become available on a limited or general basis to the operating companies, performance data is fed back in three formal ways.

One way is the Engineering Complaint Process. If the item is available on a limited basis, such as during field trials, performance exceptions are submitted to the original development group or field trial team. If the item is generally available, performance exceptions are submitted to the Department Engineer, the Western Electric Field Representative, and the BTL Field Representative.

A second way to feed back performance data is through the Trouble Ticket and Trouble Coding System. Failures, outages, repair actions, and causes are sent to 195. A computerized reporting system maintained by 195 performs many types of analysis, including cross-departmental analysis.

The third formal feedback mechanism is through the Routine Maintenance Reporting System. BTL prescribes routine maintenance and publishes maintenance practices and Task Oriented Plant Practices (TOPPS) derived and updated, in part, from reviewing routine maintenance reports.

4.7 Standardization

The Bell System is one of the few organizations that standardize at the module level. Although Bell recognizes the inherent dangers of equipment standardization above the piece-part level, it also recognizes that the risks of allowing rapid technological change increase rapidly with system scale. Furthermore, BTL continually assesses the impact of large-scale standardization by means of sophisticated models that consider all pertinent factors and, because the Bell System controls all aspects of applicable technological growth, it is possible to tailor the standardization policy accordingly.

4.8 System Redundancy on a Local and National Scale

The Bell System has taken advantage of national and local redundancy allocation for many years.

National-level redundancy patterns are planned and implemented by the Long Lines Department. This department has total responsibility for coordinating regional and national (and international) interconnection requirements. More significantly, Long Lines also has separate and distinct budgetary authority as well as separate and distinct profit and loss responsibilities (i.e., through the "toll" approach). Therefore, Long Lines can and does act as an advocate for national-scale redundancy and can back up its position rather effectively in opposition to advocates of local redundancy, if required. Although the cost-effectiveness of national vs. local redundancy patterns is controversial, Bell people believe that it is important that advocates of national-level redundancy have at least as much economic and technical power as local advocates if cost-effective compromises are to evolve in time to cope with "high-cost-of-local-redundancy" problems as they occur.

Local-level redundancy patterns typically evolve in response to the peculiar characteristics of local demand. Since the early 1930s, the principal determinants have been -- first, the trend toward urbanization and, subsequently, the trend toward urban sprawl. During the sprawl stage the need for more intra-regional redundancy became evident in some areas of the country (e.g., the Northeast Corridor) at about the same time as needs for intra-national redundancy became apparent. As one result, the former emphasis on local (i.e., state-by-state) regulation became a deterent to cost-effective, "integrated" redundancy at all levels (e.g., the Nevada "rusty switch").

Both viewpoints, the local and national, are centrally addressed by BTL. In performing this function, BTL provides inputs to both the long lines and local planning processes. Furthermore, BTL is able to act as

referee in the bi-advocate process by providing sophisticated analytic help to both parties. BTL considers economic and technical alternatives at all levels.

5. COST AND EFFECTIVENESS

The Bell performance assurance program has survived and evolved over many years in a very efficient and highly structured environment, and appears to be cost-effective in that environment. However, we were not able to obtain enough explicit and quantitative information to provide an objective measure.

5.1 Cost of Performance Assurance at Bell

Bell spends a substantial percentage of its budget for new systems on performance assurance. When one considers the reports published by BTL and the fact that many prototypes undergo extensive field trial, it appears that performance assurance costs at Bell may be very high relative to prototype acquisition costs for complex systems (e.g., electronic switches). However, once prototype performance has been assured, the system is standardized and manufactured on a semi-mass-production basis. Furthermore, the production systems are designed for very long life and depreciated over many years. Thus, the cost of performance assurance relative to the cost of total plant is probably very small.

5.2 Effectiveness of Bell's Performance Assurance Program

The Bell System's low cost to consumers and dependable service is evidence that Bell's program is reasonably effective from a life-cycle-cost viewpoint. However, there is considerable controversy whether the Bell approach maximizes availability, reliability, and maintainability and minimizes redundancy in an optimum way.

The Bell System program appears to be very effective in uniting and focusing national as well as local efforts. Furthermore, most of the high risks are assumed at the nonlocal level (by AT&T through BTL). These risks are allocated equally to all local levels and spread over long periods of time (via pricing policies which explicitly recognize new system development costs).

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This report provides an overview of performance assurance practices developed and applied since World War II to improve the cost-effectiveness of selected, large-scale technological systems. The purpose is to present concepts which might be applicable in reducing the frequency and duration of electric powerplant outages. A comprehensive performance assurance program is recommended. The elements of the suggested program were derived by considering elements of precedent programs which are

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